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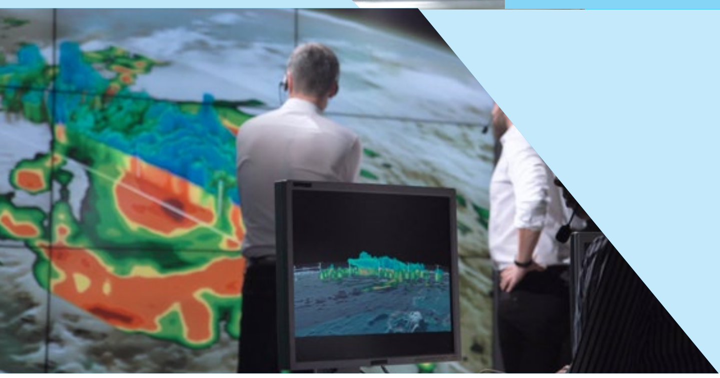
Information and communication technologies and the environment



Output Report on ITU-D Question 6/2

Information and communication technologies and the environment

Study period 2018-2021

Information and communication technologies and the environment: Output Report on ITU-D Question 6/2 for the study period 2018-2021

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The study groups of the ITU Telecommunication Development Sector (ITU-D) provide a neutral platform where experts from governments, industry, telecommunication organizations and academia from around the world gather to produce practical tools and resources to address development issues. To that end, the two ITU-D study groups are responsible for developing reports, guidelines and recommendations based on input received from the membership. Questions for study are decided every four years at the World Telecommunication Development Conference (WTDC). The ITU membership, assembled at WTDC-17 in Buenos Aires in October 2017, agreed that for the period 2018-2021, Study Group 2 would deal with seven Questions within the overall scope of "Information and communication technology services and applications for the promotion of sustainable development."

This report was prepared in response to Question 6/2: **Information and communication technologies and the environment** under the overall guidance and coordination of the management team of ITU-D Study Group 2 led by Mr Ahmad Reza Sharafat (Islamic Republic of Iran), as Chairman, supported by the following Vice-Chairmen: Mr Nasser Al Marzouqi (United Arab Emirates)(resigned in 2018); Mr Abdelaziz Alzarooni (United Arab Emirates); Mr Filipe Miguel Antunes Batista (Portugal)(resigned in 2019); Ms Nora Abdalla Hassan Basher (Sudan); Ms Maria Bolshakova (Russian Federation); Ms Celina Delgado Castellón (Nicaragua); Mr Yakov Gass (Russian Federation)(resigned in 2020); Mr Ananda Raj Khanal (Republic of Nepal); Mr Roland Yaw Kudozia (Ghana); Mr Tolibjon Oltinovich Mirzakulov (Uzbekistan); Ms Alina Modan (Romania); Mr Henry Chukwudumeme Nkemadu (Nigeria); Ms Ke Wang (China); and Mr Dominique Würges (France).

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Executive summary

This Output Report on Question 6/2 entrusted to Study Group 2 of the ITU Telecommunication Development Sector (ITU-D) for the study period 2018-2021 offers an overview of the growing challenge of e-waste and presents existing solutions for the safe disposal and use of this waste stream. It focuses on the role and implementation of technology in the context of climate action, climate-change mitigation and adaptation and monitoring of the climate, as well as information and communication technology (ICT) solutions for improved and efficient sustainable development.

It is projected that information and communication technologies (ICTs) will be the primary facilitator in climate-change mitigation and adaptation. These include frontier technologies such as artificial intelligence, Earth observation and big data that will offer the possibility of keeping the growing temperature fluctuations in check and will improve processes for waste treatment, sanitation and renewable energies. ICTs become essential instruments, for example, in the quest for affordable and clean water, for monitoring and mitigating natural disasters/hazards, and for food production and food security.

Climate change and climate variation have an overall effect on our day-to-day lives. Our health, infrastructure, water resources, rain patterns, agriculture patterns, coastal zones and safety are all affected by climate change. This report also focuses on the practical adaptation of new-age technologies for climate-change mitigation in addition to how they affect the environment both directly and indirectly.

The studies carried out under Question 6/2 identified the problems associated with e-waste and climate change, including global and regional stakeholders and priorities, focusing on data collection, case studies, best practices and policies, and sustainability. The outcome of previous initiatives was also studied, and regional needs, including common policies and work plans that can be tailored to the specific needs of Member States, were discussed. Regional and national success stories and best practices were examined, and workshops were organized to discuss the latest developments and compare policy. Stakeholders, including governments, policy-makers, civil society, academia, regulators and various organizations, were involved throughout.

Some best practices, policies and country-specific case studies presented at the ITU-D Study Group 2 Question 6/2 meetings during the 2018-2021 study cycle are included in this report. References to other ITU Sector reports are also given.

Chapter 1 provides an overview of e-waste, the global patterns and trends in the increase of e-waste, as well as a description of various organizations and initiatives that aim to address e-waste.

Chapter 2 focuses on education and awareness, hazards posed by e-waste to human health and the environment, the significance of proper management of e-waste and the disposal process, along with consumer actions to reduce e-waste.

Chapter 3 focuses on developing e-waste strategies, recycling, e-waste take-back systems, public/private participation and government initiatives. Various financing models for e-waste take-back systems to prevent e-waste and ensure it remains economically viable are also discussed in addition to case studies, best practices and policies for e-waste collection from stakeholders, including secure transportation and storage, safety standards and training of the informal sector involved in the manual dismantling and handling of e-waste, as well as the economic viability of recycling and reuse.

Chapter 4 focuses on new technologies, systems and applications to monitor the climate and reduce its impact. The chapter shows how big data and artificial intelligence can be instrumental in convincing policy-makers and industry leaders of the importance of environmental challenges in addition to bringing transparency and clarity to new policies, for governments and industry, and setting new standards of production and reduction of emissions. The output of such an analysis can help emerging economies adapt, strengthen and develop effective adaptation policies, strategies and systems to overcome scenarios of extreme weather conditions. This chapter also underlines the difficulties in monitoring climate change in developing countries, as no common metrics are available to gauge the social and economic costs of climate change faced by emerging economies.

Chapter 5 focuses on guidelines, technologies and development of best practice on climate-change monitoring and mitigation strategies and discusses the role of Earth observation (satellites, sensors, etc.), which provides accurate weather forecasts and helps emerging economies plan development goals by responding to changing weather patterns.

Abbreviations and acronyms

ACSIS	African Civil Society on the Information Society
AI	artificial intelligence
ANN	artificial neural network
AR / VR	augmented reality/virtual reality
BDT	Telecommunication Development Bureau
DL	deep learning
DVD	digital video disk
ECOWAS	Economic Community of West African States
EEA	European Economic Area
EEE	electrical and electronic equipment
EMG	Environment Management Group
EIT	European Institute of Innovation and Technology
EPR	extended producer responsibility
EU	European Union
GB	gigabytes
GEM	Global E-waste Monitor
GeSI	Global e-Sustainability Initiative
GESP	Global E-waste Statistics Partnership
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GPS	Global Positioning System
GPU	graphical processing unit
ICT	information and communication technology (plural ICTs)
IDC	International Data Corporation
IDMC	Internal Displacement Monitoring Centre
IETC	International Environmental Technology Centre
ILO	International Labour Organization
IoT	Internet of Things
IPv4	Internet Protocol fourth version

(continued)

IPv6	Internet Protocol sixth version
ISWA	International Solid Waste Association
ITC	International Trade Centre
ITU	International Telecommunication Union
LCD	liquid crystal display
LDC	least developed country
M2M	machine-to-machine
M2P	machine-to-people
MDP	Markov decision process
ML	machine learning
MOOC	massive open online course
MSME	micro, small and medium-sized enterprise
Mt	metric tonne
NOAA	National Oceanic and Atmospheric Administration
OECD	Organisation for Economic Co-operation and Development
PRO	producer responsibility organization
PVC	polyvinyl chloride
R&D	research and development
RL	reinforcement learning
SaaS	software as a service
SDGs	Sustainable Development Goals
StEP	Solving the E-waste Problem initiative
TSB	Telecommunication Standardization Bureau
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UNITAR	United Nations Institute for Training and Research
UNU	United Nations University

(continued)

WEEE	waste electrical and electronic equipment
WHO	World Health Organization
WMO	Word Meteorological Organization
WWA	World Weather Attribution
WWF	World Wide Fund for Nature
XML	extensible mark-up language

Chapter 1 – Background on e-waste

Discarded electrical and electronic equipment (EEE) (such as phones, laptops, fridges, sensors and TVs) is referred to as e-waste, or waste electrical and electronic equipment (WEEE). The majority of e-waste is made up of personal or household devices such as computers, smart devices, screens, televisions and tablets as well as heating and cooling appliances.[1]

Direct or indirect exposure to e-waste, from physical contact to inhalation of toxic fumes, is a health risk for humans and animals. An accumulation of e-waste in the soil, water, air and other natural resources can pass through the food chain and give rise to many toxic by-products, which metabolize at a very slow rate in the human body and can cause long-term harm, including cancer, immune deficiency disease, respiratory and hormonal disorders, birth defects and infant mortality. Most vulnerable to the health risks posed by e-waste are children and young adults, as their bodies are still developing.[2]

Global growth of e-waste

Due to higher consumption rates of EEE, short life cycles, and fewer and costly repair options, e-waste is the world's fastest-growing domestic waste stream.

According to the Global E-waste Monitor 2020, in 2019:

- around 53.6 million metric tonnes (Mt) of e-waste were produced worldwide, a 21 per cent increase since 2014, and it is estimated that by 2030 global e-waste figures will reach around 74 Mt;
- only 17.4 per cent of e-waste was being collected and recycled, thus creating a huge loss of high-value and precious metals (such as gold, silver, copper and platinum) with an estimated value of about USD 57 billion, higher than the gross domestic product of most countries;
- the Asia-Pacific region generated the highest volume of e-waste (24.9 Mt), followed by the Americas region (13.1 Mt) and the Europe region (12 Mt), whereas the Africa region generated 2.9 Mt.[3]

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1 Electrical and electronic equipment constitutes a wide variety of products, including any household or business item containing circuitry or electrical components, with a power or battery supply (StEP Initiative).
2 World Health Organization (WHO). E-waste on children's health.
3 ITU. Global E-waste Monitor 2020.

Figure 1: E-waste volume status and prediction[4]

Source: ITU

ITU and e-waste initiatives

The International Telecommunication Union (ITU) is the United Nations specialized agency responsible for many issues concerning ICTs and telecommunication operations and services worldwide. In 2018, the Plenipotentiary Conference, which is the highest policy-making body of ITU, established targets regarding e-waste that strive to increase the global e-waste recycling rate to 30 per cent and to raise the percentage of countries with e-waste legislation to 50 per cent by 2023.

The ITU Telecommunication Development Bureau (BDT) has been assigned the task of assisting developing countries in undertaking proper assessment of the magnitude of e-waste and carry out pilot projects, to achieve environmentally sound management of e-waste through e-waste collection, dismantling, refurbishment and recycling, as well as a lifecycle approach to electronic products. This task is set out in Resolution 66 (Rev. Buenos Aires, 2017) of the World Telecommunication Development Conference, on ICT and climate change.

[4] ITU. Electronic waste is a growing challenge. What can you do to help? *ITU News*, 21 June 2018.

The Global E-waste Statistics Partnership

The Global E-waste Statistics Partnership (GESP)[5] was founded in 2017 by ITU, the United Nations University (UNU) and the International Solid Waste Association (ISWA) to monitor developments of e-waste over time, and to help countries to produce e-waste statistics. The initiative will inform policy-makers, industry, academia, media and the general public by enhancing the understanding and interpretation of global e-waste data and their relation to the Sustainable Development Goals (SDGs).

ITU and e-waste policy support

To assist ITU Member States to balance their economic and social development with their environmental management, ITU provides a programme dedicated to policy and regulatory development. Member States can request ITU technical assistance and capacity building to support national or regional WEEE policy development.

"*Step One – Official Request:*

Member States should make an official written request directly to their ITU Regional Office, requesting WEEE policy technical assistance.

Step Two – Task Team:

If they have not already done so, Member States are advised to establish a task team dedicated to WEEE policy development. This team would include government representatives from at least ICT, environment and health.

Step Three – Country Profile:

ITU creates a country profile with an overview of environment, society, economy, the existing regulatory landscape and WEEE management infrastructure. An extensive literature review, trade data and any waste generation or collection figures are compiled.

Step Four – Online Module:

E-learning module provided to all national public stakeholders with an introduction to key e-waste concepts. This self-paced introduction aims at preparing stakeholders for e-waste policy development.

Step Five – Stakeholder Surveys:

Qualitative surveys are circulated to all stakeholders from government and non-government. They form the start of consultations and national WEEE assessment.

Information is sought on the roles and responsibilities of different actors, financing and enforcement, infrastructure and product scope.

5 GESP: https://globalewaste.org/

Step Six – National Assessment:

ITU works with Member States to conduct either an in-depth or a rapid national WEEE assessment, depending on national preferences, commitment, existing information and the foreseen policy development timeline. National assessment generally comprises:

- *Bilateral consultations in-person with all relevant stakeholders following the surveys*
- *Site visits to take note of existing WEEE infrastructure or similar waste activities*
- *National stakeholder consultation workshop to initiate formulation of the draft policy*

Step Seven – Preparatory Drafting:

ITU assists with technical writing as part of the transition from stakeholder consultation to policy drafting.

Step Eight – Policy Validation:

A validation workshop provides stakeholders with an opportunity for final consultation, before policy consensus.

Step Nine – Implementation Plan:

ITU supports the government to ensure that roles and responsibilities, resources, objectives and timelines are allocated to safeguard policy implementation. Where applicable, implementation planning is undertaken in line with national guidelines for policy development."[6]

ITU role in e-waste advocacy and media awareness

ITU raises awareness through blogs and social media forums of public policy initiatives to address the global e-waste challenge and stakeholder engagement. ITU is also involved in hosting and co-organizing various events and thematic dialogues on e-waste. Since 2019, ITU has supported the organization of International E-Waste Day,[7] which takes place each year in October, to raise public and media awareness of e-waste and recycling. International E-Waste Day was instituted in 2018 by the WEEE Forum[8] with the support of its members. On 14 October 2019, the second International E-Waste Day was celebrated by ITU with 112 organizations from 48 countries participating.

Telecommunication Standardization Bureau (TSB) and e-waste

The ITU Telecommunication Standardization Bureau (TSB) supports the work of the ITU Telecommunication Standardization Sector (ITU-T).[9] TSB facilitates and organizes the process of approval of ITU-T Recommendations and manages agreements between other international standards development organizations and ITU in order to have common standards and avoid duplication of work between stakeholders. Such agreements further strengthen the role of ITU in the field of standardization in the telecommunication sector.

ITU-T sets standards for telecommunication equipment and systems and publishes best practices and guidelines for developing sustainable and green ICT solutions, such as green

6 ITU. Brochure for Member States. Waste Electrical and Electronic Equipment Policy Development.
7 WEEE Forum. International E-Waste Day (IEWD)
8 WEEE Forum: https://weee-forum.org/who-we-are/
9 ITU-T. ITU-T in brief

battery solutions, universal power adapters and charger solutions for mobile terminals and other handheld ICT devices, and external universal power adapter solutions for stationary ICTs. ITU-T sets out the procedures for recycling rare metals present in ICT goods and drafts best practices for green data centres along with guidelines towards developing sustainable e-waste management systems. For the current study period (2018–2020), work on environment, climate change and circular economy is entrusted to ITU-T Study Group 5.[10]

UN E-Waste Coalition

The UN E-Waste Coalition[11] was created in 2019 on the joint signing of a letter of intent which is non-binding on the signatories. It comprises a group of UN agencies that aim to provide more efficient support to address the e-waste challenge in Member States.

The coalition includes: ITU, the International Labour Organization (ILO), UN Environment, the United Nations Industrial Development Organization (UNIDO), the United Nations Institute for Training and Research (UNITAR), UN Habitat, the United Nations University (UNU) and the secretariats of the Basel and Stockholm conventions. It is supported by the World Health Organization (WHO) and coordinated by the Secretariat of the Environment Management Group (EMG). It paves the way for a coordinated effort to visualize and conceptualize proposals; to increase commitment and engagement with manufacturers and recyclers of electronic goods; to formulate projects and have trial runs to address e-waste management activities; to encourage partnerships between the public and private sectors; and to encourage knowledge sharing and provide data and statistics for real-time tracking of e-waste.

Secretariat of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal

The Basel Convention[12] is an international treaty that came in force in 1988 and, by 2018, had 186 Member States and the European Union as signatories. Its purpose is to control transboundary movements of hazardous wastes between nations and their disposal, focusing on prevention of transfer of hazardous waste from developed to underdeveloped or least developed countries (LDCs) to assist them in environmentally friendly management of hazardous waste. It also provides technical guidelines to LDCs, though movement of radioactive waste does not come under its purview.

United Nations Environment Programme (UNEP)

The International Environmental Technology Centre (IETC),[13] under the United Nations Environment Programme (UNEP), is working towards sustainable waste management, focusing on reports and guidelines on e-waste management strategies and engaging with local and national governments. UNEP helps in capacity building by providing knowledge support to develop future roadmaps for e-waste management.

UNEP publications include: "E-waste Volume I: Inventory assessment manual", "E-waste Volume II: E-waste management manual", "E-waste Volume III: WEEE/e-waste take-back system",

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[10] ITU-T. Study Group 5: Environment, climate change and circular economy
[11] ITU. UN E-Waste Coalition
[12] United Nations Environment Programme (UNEP). Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal
[13] UNEP. International Environmental Technology Centre (IETC).

"Compendium of technologies for the recovery of materials from WEEE/e-waste" and "E-waste foresight report (2019)".[14]

UNEP, in collaboration with the Basel Convention, the World Resources Forum, the University of Leuven, EIT Raw Materials and the European Multiple MOOC Aggregator, is initiating an open online training course on e-waste (MOOC).[15]

World Health Organization (WHO)

The World Health Organization (WHO) is involved in awareness generation to educate the world about adverse effects of e-waste on health, especially of children, and the need to safeguard children from exposure to hazardous waste.[16]

WHO is also involved in R&D to promote research on the harmful effects of e-waste and monitor health effects of exposure to e-waste. It also promotes awareness of the impact of exposure to e-waste on health both globally and regionally, and provides policy interventions and solutions to countries and to the health sector. WHO is focusing on pilot projects in collaboration with UN agencies such as UNIDO to formulate child health protection frameworks for developing countries.

International Labour Organization (ILO)

In 2019, government representatives from across the world, many employer and worker organizations and non-governmental organizations met in Geneva to build consensus on a decent and safe work environment for workers handling e-waste. The points of consensus that were adopted called for governments to encourage investment in waste-management infrastructure and support structures at all levels, to provide a decent work environment, and to safeguard against hazards posed by e-waste for human health, highlighting the vulnerability of workers and their families involved in handling e-waste in developing countries.

The need for improved equipment to extract metals from e-waste, formalization of the informal sector and better coordination between government agencies to prevent health hazards from e-waste was underlined, as well as the need for a set of guidelines or a code of practice in the management of e-waste.[17]

United Nations University

The United Nations University (UNU) has its headquarters in Shibuya, Tokyo, Japan. UNU is the academic and research branch of the United Nations. Through collaborative research and education, it works to resolve global issues related to human development and welfare. UNU is involved in knowledge transfer of research and scientific advances and innovative technologies. UNU encourages interdisciplinary research and provides cutting-edge and targeted policy solutions, focusing on sustainable development policies.[18]

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14 UNEP. IETC. Resources
15 UNEP. E-learning. E-Waste Challenge. 2 November 2017.
16 WHO. Op. cit.
17 ILO. Waste management sector. ILO's first ever meeting on e-waste adopts Points of Consensus to promote decent work in the sector. ILO News, 11 April 2019.
18 UNU: https://unu.edu/

UN Habitat

The United Nations Human Settlements Programme (UN Habitat) focuses on sustainable urban development. It is part of the e-waste coalition "paving the way for coordination and collaboration on UN system-wide support for e-waste management".

United Nations Industrial Development Organization (UNIDO)

This UN specialized agency based in Vienna, Austria, works in around 60 countries. The UNIDO e-waste initiative focuses on providing assistance to countries in the field of economic and industrial development to encourage the development of a sustainable e-waste recycling industry in emerging economies and to promote an environmental service industry in developing countries.[19]

International Trade Centre (ITC)

The International Trade Centre (ITC) promotes inclusive and sustainable economic growth and development in emerging economies, especially in LDCs and economies in transition, through capacity building in international competitiveness of micro, small and medium enterprises (MSME). E-waste is often handled by small producers in developing countries, who face challenges in establishing formal businesses which are competitive and sustainable. ITC is engaged in awareness generation among regional and international stakeholders regarding e-waste challenges, including research and development on the primary challenges faced in the e-waste trade value chain, the promotion of a circular economy across sectors for e-waste management, and the prevention of illegal transborder trade.[20]

Other organizations

International Solid Waste Association (ISWA)

The International Solid Waste Association (ISWA) promotes and supports resource efficiency through sustainable production and consumption in developing and emerging economies. ISWA also contributes to the development of waste management through capacity building and education.[21]

European Union initiatives on e-waste escalation

The short lifecycle of electronic devices, often because the cost of repair is high or it is cheaper to buy a new device, is leading to an accumulation of e-waste. In 2019, the European Union took action to reduce the accumulation of e-waste and to fulfil the circular economy vision by working on new laws requiring manufacturers to ensure that appliances are easier to repair and have a much longer functional life. The European Commission wants to implement a new design directive to reduce the estimated 12 million tons of e-waste per year by increasing the lifespan of electronic devices.

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[19] UNIDO. Electronic Waste (e-Waste).
[20] ITC. IT E-Waste Policy.
[21] ISWA. To Promote and Develop Sustainable and Professional Waste Management Worldwide and the transition to a Circular Economy.

Extended producer responsibility (EPR)

The concept of extended producer responsibility (EPR) was first developed in the 1990s. The Organisation for Economic Co-operation and Development (OECD), for example, defines EPR as an environmental policy approach in which producer responsibility for a product is extended to the post-consumer stage of a product lifecycle. At the national level, regulatory frameworks incorporate the principles of EPR, often by enforcing producer 'take-back' and consumer 'bring-back' obligations for e-waste The EPR mechanism allows the sharing of responsibilities in dealing with waste problems. Under the EPR system, producers share the role of promoting recycling with consumers and governments. EPR also includes producers subsidizing the recycling business. In general, the recycling business does not enjoy commercial profits for a variety of reasons. For example, the products of recycling businesses, mostly recycled materials, are sometimes at a disadvantage vis-à-vis virgin materials in terms of quality as well as price. Without appropriate compensation, private businesses struggle to engage in the recycling business. EPR should provide subsidies and assistance to private recycling businesses to enable them to make a profit.

Producer responsibility organization (PRO)/compliance scheme

A producer responsibility organization (PRO) takes on the responsibility of operational aspects of waste collection, transportation, environmentally sound recycling and disposal of end-of-life products on behalf of producers, to meet EPR obligations. Whereas a PRO is founded by producers collectively, a compliance scheme is normally a for-profit company set up as a service provider to producers.

A PRO is established with the support of manufacturers that produce EEE and helps manufacturers, importers and retailers comply with EPR obligations. Governments sometimes stipulate a set of targets for reuse and recycling of products as part of EPR in order to monitor the impact of EPR and producer performance in relation to the volume of production. On behalf of its members (manufacturers, importers, distributors, retailers), a PRO provides reporting and compliance. The functioning of an EPR system should be managed by a PRO and registered producers, and should have a suitable self-financing mechanism to meet EPR obligations.[22]

Challenges to implement EPR in emerging economies

Implementation of EPR worldwide is a difficult task due to the lack of collection infrastructure and established recycling and refurbishing facilities that conform to international standards. For successful EPR implementation, proper monitoring and pricing mechanisms are required to make EPR more lucrative and profitable.

Online buy-back schemes also need to be more financially viable to motivate consumers to use authorized recyclers, and scaling-up of recycling infrastructure to deal with the amount of recycled and refurbished products is required to fill gaps in the electronics supply chain.

Looking forward

Government initiatives, including e-waste handling, disposal, awareness generation and assigning responsibility to various actors in the e-waste value chain such as producers (manufacturers,

[22] For example, see: Packing Recovery Organisation (PRO Europe): https://www.pro-e.org/

importers, distributors, retailers), recyclers (collectors, pre-treatment facilitators), consumers (bulk and household) and governments (local and national), will increase the economic and growth potential of the sector.

According to the Global E-waste Monitor 2020[23] (see **Figure 2**), the number of countries that have adopted a national e-waste policy, legislation or regulation has increased from 61 to 78 between 2014 and 2019. In many regions, however, regulatory advances are slow, enforcement is low, and the collection and proper e-waste management is poor. As indicated earlier, ITU Member States have also set a target to raise the percentage of countries with e-waste legislation to 50 per cent – or 97 countries – by 2023, and ITU provides a programme dedicated to e-waste policy and regulatory development, where Member States can request technical assistance and capacity-building support.

Figure 2: Countries with e-waste policy, legislation or regulation

Source: ITU

The process of developing new and inclusive non-sector-specific legislation needs to be streamlined, and enforcement and monitoring of existing policy and legislation should be strengthened. For example, where the ministry of the environment is the main policy-maker, it can act as regulator for policy implementation and streamline the procedure of e-waste management; whereas decentralizing e-waste management responsibility to, for example, the ministries of telecommunications, labour, trade and health, which are key sectors in the escalation of e-waste, can reduce the impact of e-waste management policy and legislation by making e-waste management sector specific.

As with solid waste management, the concept starts with the waste hierarchy. The first focus should be on the prevention of e-waste, followed by reduction, reuse, recycling, recovery and disposal. Product design can also play a key role, especially in regard to the end-of-life phase of product lifecycles, by reducing waste through design. Provision of financial support and tax incentives should be part of policy, along with strong emphasis on skills development of the informal e-waste sector, providing resources and infrastructure for scientific disposal and reuse and refurbishing, and encouraging better product design and quality.

Natural resources are limited, and reclaiming them through scientific management of e-waste is a viable solution since e-waste can contain copper, iron, aluminium, gold, silver and palladium. There are also rarer earth metals for which demand is growing due to the increase in demand

[23] Vanessa Forti et al. The Global E-waste Monitor 2020: Quantities, flows, and the circular economy potential. UNU/UNITAR – co-hosted SCYCLE Programme. ITU and ISWA. Bonn/Geneva/Rotterdam, 2020.

for electronic vehicles and consumer electronics, such as neodymium and dysprosium which are used in manufacturing magnets and batteries. A single approach will not fit all system stakeholders and flexibility in product design and innovative methods of e-waste disposal is important. National e-waste regulatory models vary, for example e-waste disposal in Cameroon is financed by producers, while in Switzerland consumers contribute to the cost of disposal.

The Government of India[24] recognizes the economic potential and contribution of e-waste towards India's resource strategy and circular-economy vision, as well as recognizing the "human element" at the centre of e-waste management. The Economic Advisory Council to the Prime Minister of India is monitoring the various agencies and state governments involved in e-waste management. A policy awareness workshop on e-waste[25] for capacity building was organized in 2019 by the office of the principal scientific adviser, cabinet secretariat, along with ITU, ILO, UNU and WHO. In India, researchers under the Waste Management programme of the Department of Science & Technology (DST) have held successful laboratory trials of pyrolysis of e-waste, a process through which e-waste is converted into solid, liquid and gaseous forms, and precious metals are recovered in solid form while other products are used as fuel.[26]

Similarly, the Tokyo Organizing Committee of the Olympic and Paralympic Games launched the hugely successful "Tokyo 2020 Medal Project" calling upon citizens to collect used small handheld devices from across Japan to produce the medals for the Games. Citizens were consulted in the design and almost 5 000 medals have been made from recycled metals (see **Figure 3**).

Figure 3: Tokyo 2020 Medal Project

Source: Tokyo Organizing Committee of the Olympic and Paralympic Games

To tackle e-waste, countries will have to rethink solid waste management policy. E-waste, along with heavy metals and hazardous waste, need to be segregated and sent for recycling at the

24 ITU-D SG2 Document 2/281 from India
25 ITU. Policy awareness workshop on e-waste. Hyderabad, India, 27-29 November 2019.
26 Indus Dictum. IIT Delhi scientists develop tech to recycle e-waste, recover gold and precious metals. 7 December 2019.

collection stage. Since e-waste collection in emerging economies is heavily dependent on the informal sector, it is imperative to ensure safe conditions and appropriate skills, along with cost-effectiveness and standards, for this sector. Exhaustive solutions are needed for eco-friendly and sustainable e-waste management. End-to-end e-waste recyclers, and metal extractors need to be promoted to maximize value recovery. The correct policy mix can encourage employment generation in the sector. In most emerging economies, e-waste is still recovered efficiently due to the huge market for second-hand products, which reduces e-waste. Supporting infrastructure, timely implementation of policies and regulations and technology advancement can prevent e-waste from escalating while recovering precious limited natural resources. E-waste monitoring and reduction targets should be set by stakeholders, as well as building multistakeholder partnerships between the public and private sectors for consolidated action.

Chapter 2 – Education and awareness on e-waste

2.1 The importance of disposing of e-waste properly and the consequences of not doing so for the environment and human health

Management of e-waste continues to cause enormous environmental and health-related problems for the professionals involved in this activity and the population as a whole. ICT waste is a concern as it contains toxins such as mercury, cadmium, lead, arsenic and beryllium, which are very harmful to public health and the environment if not handled properly. Furthermore, telephones contain large quantities of materials that can be hazardous to the environment and must be handled with care.

The expansion of ICTs in the Africa region is accompanied by the increased generation of e-waste, with multiple consequences for the environment, local communities and the economy. In 2011, a United Nations publication "Where are WEEE in Africa?"[27] reported that domestic consumption was the main factor contributing to the increase of e-waste. A study of five West African countries showed that every year domestic consumption was generating between 650 000 and 1 million tonnes of e-waste and that disposal was often through incineration in open pits and informal recycling networks with no assurance of quality, safety and environmental protection. The report also highlighted the role that imported e-waste played in aggravating the problem. E-waste encompasses a large family of devices and has been at the centre of many concerns about their social and environmental impact[28] across the whole planet.[29]

Planned obsolescence generates vast amounts of e-waste that is often exported or trafficked to regions where there is great economic and social inequality. A small number of people (in government and industry) benefit, to the detriment of the local population, which is usually heavily reliant on agriculture. In the absence of a selective waste processing industry, waste is recycled through informal systems. Since the waste is toxic, this leads to pollution which not only puts the lives of local inhabitants in danger but also affects ecosystems that are a source of welfare and income for them.

For example, exposed to the elements, discarded electronics release the lead used in printed circuits and cathode ray tubes and the mercury used for backlighting LCD screens, as well as cadmium, chromium and even chemical reagents such as cyanide. According to UNEP, pollution due to discarded telephones and other e-waste is a significant human health hazard that contaminates soil, water and air.

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[27] UNEP. The Basel Convention. Where are WEEE in Africa? Findings from the Basel Convention e-waste Africa Programme. December 2011.

[28] Henri Breuil et al. Rapport TIC et développement durable. *Conseil général de l'environnement et du développement durable* (CGEDD) and *Conseil Général des Technologies de l'Information* (CGTI), 2008; and Fabrice Flipo et al. Technologies numériques et crise environnementale: peut-on croire aux TIC vertes? in *Projet Ecotic, Rapport final*, 2009

[29] Cédric Gossart C. De l'exportation des maux écologiques à l'ère du numérique. *Mouvements*, 2009, pp. 23-28

2.1.1 Environmental consequences

Three recent ITU-D Study Group 2 contributions reveal Member State concerns over environmental pollution.[30] Accumulated waste pollutes the soil, including deeper layers, the air and water (water table, water bodies) and degrades the foodstuffs derived from the food chain (milk and other agricultural products, for example). Hazards for the environment arise when devices are dismantled to extract valuable resources, and toxic substances are discarded directly into the soil. Atmospheric pollution has repercussions on local ecosystems on which local people depend for their livelihood: the burning of electrical wires, for example, contributes to the ambient air pollution and leaves behind polluting ash. Unwanted materials are often buried or simply abandoned, further polluting the environment. Some regions have very high levels of dioxins and atmospheric furans, and incineration of toxic waste (tyres, foam insulation) also depletes the ozone layer and contributes to greenhouse warming.

A 2010 scientific study on the effects of the toxic substances resulting from e-waste recycling showed that the benefits of recycling are outweighed by the pollution caused by the recycling technology, such as the release of toxic fumes directly into the environment and the pollution of water resources, the atmosphere and the biosphere.

2.1.2 Human consequences

The long list of harmful substances contained in electronic waste includes cadmium, lithium, lead, brominated flame retardants and polyvinyl chlorides. These are a serious strain on public health. Workers who come into direct contact with these chemical products lack suitable protection. They inhale dust that attacks the respiratory system (coughing, infection, shortness of breath, asthma), and causes eye irritation and skin damage. They are exposed to heavy metals (lead, mercury, cadmium, PVCs) that are carcinogenic and cause damage to the nervous system, the circulatory system, reproductive organs, the respiratory system, kidneys and bones, and when dismantling equipment they can receive electrical shocks.

Children and pregnant women are a particularly vulnerable group, suffering, for example, high mortality and reproductive health issues. Many children are recruited to collect, dismantle and incinerate EEE. Unequipped for such work, they are victims of workplace accidents and poor working conditions, and they are often stigmatized, harassed and exploited by employers. In some Africa region countries, discarded objects and scrap metal are often collected by itinerant workers referred to as *gankpo gblégblé*.[31] Some of the waste they collect ends up on scrap-heaps, where they are picked over by children without any protective equipment, looking for useful residues at enormous risk to their health.

2.1.3 Socio-economic consequences

Managing what happens at the end of the lifecycle of electrical and electronic equipment remains a major challenge. Aware of the dangers EEE represents for the public and for the economy, some countries have launched recycling efforts.

30 For more information, see ITU-D SG2 Documents SG2RGQ/119 from Cameroon, SG2RGQ/109 from Sri Lanka and SG2RGQ/198 from BDT.

31 Expression in the Fon language spoken in Benin, meaning "scrap" or ferrous metal waste

In 2014, with funding from the World Bank, Cameroon carried out a technical/economic and environmental study with a view to setting up a pilot centre for the management of WEEE. The study, which examined the issue of WEEE for the entire country, revealed that each urban household in Cameroon produces 34 kg of WEEE on average each year (i.e. 6.8 kg/inhabitant/year), of which 40.5 per cent is from audiovisual equipment, 8.5 per cent from telecommunication and IT equipment and 44 per cent from large domestic appliances (fridges, freezers, air conditioners, etc.). At present, this obsolete equipment is stored by owners, disposed of with household waste or burned by collectors (e.g. cables), causing significant emissions of dioxins and furans (toxic molecules with strong persistence in nature).[32]

In the first quarter of 2019, the government issued a call for expressions of interest for the purpose of recruiting a consultancy firm to carry out a study with a view to setting up a laboratory to analyse environmental pollution from electromagnetic waves. The results of the study will allow Cameroon to equip itself with a high-level laboratory to analyse and interpret the impact of electromagnetic radiation on the environment and the health of the people of Cameroon.

2.2 What consumers can do to reduce the production of e-waste (the 4 Rs)

The "4 Rs" strategy is being promoted by environmental stakeholders to minimize e-waste: reflect, reduce, recycle, and recover.

2.2.1 Reflect

The excessive amount of waste being generated and consumed needs to be reconsidered. Consumption addresses basic needs of food, shelter, education and entertainment, but certain factors such as income, rhythm of life, culture, education, family situation or ideas about life can influence consumer behaviour.[33] Consumption today not only meets needs but has become a key element in defining social relations. Consumption is a matter of desire, self-realization and place in society. Consumption is used to assert identity and group belonging. What people purchase is closely linked with the perception of identity. People's waste-bins say a lot about their social model and personal choices. They express an individual approach to consumption, for example: refusal to purchase, purchase of necessities, useful or unnecessary purchases, shopping for pleasure, trophy purchases.

This process of reflection requires a degree of introspection. Purchasing a product might help to construct or buttress a positive self-image; this explains the compulsive manner in which some people consume or purchase electrical and electronic devices.

Reflection is important because in a consumer society people are constantly encouraged to consume goods and services that may not be needed and which is a source of a large quantity of waste. Questioning consumption patterns might reduce negative effects such as the depletion of natural resources and the accumulation of electrical and electronic waste. People need to reflect on their consumer behaviour and become aware of the role consumption plays if the amount of e-waste generated in society is to be reduced. Reflection is the first step towards a change in consumer habits.

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32 ITU-D SG2 Document SG2RGQ/119 from Cameroon

33 For more information, see the study Gestion des déchets dans une approche d'éducation permanente, Brussels, 2014.

2.2.2 Reduce

Reduction of e-waste presupposes that the consumer exercises discernment at the stage of consumption. This needs to become an automatic reflex. As ecologically responsible citizens, consumers should always ask themselves if it is necessary to consume so much and produce so much e-waste.

Projects and initiatives can reduce the generation of waste at source, such as initiatives for responsible consumption, eco-consumption, simplicity and negative waste growth. Reducing e-waste means changing the way people consume by placing less importance on possessions, because the objective of zero waste is not recycling but rejecting things that fill waste-bins.

Reducing waste also means refusing to throw things out and purchase new things. The tendency today is to replace an item as soon as it is damaged or breaks down, although it may be possible to repair it. Repairing an item is sometimes more expensive than purchasing a replacement, and the skills needed to repair items are increasingly rare. Reducing consumption therefore means recognizing the value of those skills, sharing them and passing them on to others.

2.2.3 Reuse

The aim is to increase the circular economy and keep electronic equipment in circulation longer before being discarded. This method is prevalent in emerging economies as use of second-hand products is more common. Encouraging responsible consumerism and the practice of reuse of electronic products in addition to extended producer responsibility, where buy-back systems of old products can further encourage reuse of materials utilized for manufacturing EEE, can mitigate the problem of the ever-increasing rise in e-waste.

2.2.4 Recycle

Recycling means recovering discarded material and transforming it through an industrial process to create a new product. The material to be recycled is collected, sorted and treated, and then re-injected into a manufacturing process in lieu of a raw material. Recycling extracts value from e-waste, typically by means of chemical treatment that completely transforms the residual material. In the case of computer equipment, for example, this could involve finding a use for the plastics.

The recycling of e-waste involves four stages:

- *Collection* consists of operations that are required to gather waste from where it is generated and transport it to a treatment facility.
- *Dismantling* removes components that contain dangerous substances, such as cathode-ray tubes, batteries or discharge lamps, to facilitate access to potentially valuable subassemblies or components. This includes electronic circuit boards, a source of precious metals; cathode-ray tubes and other potentially hazardous components; plastic cases, as inputs for plastic recycling; and metallic components such as iron, copper and aluminium present, for example, in cabling, windings and cases.
- *Crushing* is a key stage in e-waste recycling, the aim of which is to reduce solid waste items in size to produce smaller fragments.
- *Separation* is an important stage in the process of recycling e-waste. For example, magnetic separation is used to remove metallic substances from the mass of crushed material when necessary.

A number of countries are introducing e-waste management methods. Thus, the Telecommunications Regulatory Commission of Sri Lanka, as the regulator for the telecommunication and ICT sector, has developed strategies and guidelines to encourage industry players and the public to reuse or properly dispose of telecommunication/ICT waste.

The following activities have been carried out in Sri Lanka:

- Action has been taken to establish a laboratory to examine standards for imported mobile phones and related ICT equipment.
- A special review of methodologies for the proper disposal of e-waste has been conducted and the results have been submitted to ITU.
- The methodologies for the appropriate disposal of e-waste have been discussed with the chief executive officers of all telephone companies in Sri Lanka. During the discussions, it was decided to keep receptacles for the disposal of waste at all telephone consumer service centres and to prepare programmes for raising awareness among consumers (see **Figure 4**).
- The telephone companies have conducted programmes on the collection of e-waste at the consumer services centres and collected waste has been sent to the waste collection centres of the Central Environmental Authority.[34]

Figure 4: E-waste awareness leaflet in Sri Lanka

Source: Telecommunications Regulatory Commission of Sri Lanka

2.3 What needs to be done to manage e-waste generated by bulk and individual consumers

To reduce the amount of e-waste being generated, it is important to look first at the used-device market before buying new equipment; it may be possible to reuse a device already in circulation. This option should be considered when new (used) equipment is to be purchased,

[34] ITU-D SG2 Document SG2RGQ/109 from Sri Lanka

or when equipment that has become unusable or obsolete for the owner is to be replaced (gifting, resale).

For a business, it is important to examine and specify the company's needs, in cooperation with the purchasing service, to establish if it is really necessary to replace the equipment. This step helps to limit unnecessary purchases, to make plans regarding the ultimate fate of the equipment that is to be replaced (transfer it to another service, gift it, sell it), and to come up with options for the purchase of used equipment when such purchases are essential, whether it be locally (other companies in the area) or on the Internet. For example, in France there are many initiatives aimed at making waste management easier for the public.[35]

A management structure (clearing house) that reflects the principles of waste reduction should be put in place, whereby a national framework (similar to those in place in France and Italy, for example) will bring stakeholders (EEE producers, recyclers and waste-management operators) together in the management of WEEE. Governments should set up and maintain a register of e-waste cycle stakeholders, define means for determining what e-waste is to be collected and processed by stakeholders, and establish and run a compliance monitoring system.

Local residents can also play their part by organizing a system for collecting household e-waste, providing collection places and conducting awareness campaigns to alert people to the challenges represented by e-waste and the solutions available. This service could be financed by a waste removal tax, as for any household waste.

The way waste collection is organized varies from country to country, as it depends on contextual factors such as socio-demographic characteristics, waste selection capabilities, the availability of local collection points, the e-waste collection legacy, population density and so on. When consumers purchase EEE, they should be required to pay a disposal tax or a visible fee that can be recovered by distributors and manufacturers to fund the eco-organizations that collect and process e-waste. Consumers should be encouraged to take their waste to collection points made available by local government, in municipalities, cities and villages.

Consumers may also be given the option of turning in their old electronic device to hi-tech retailers on a one-for-one basis, when purchasing a replacement, as described in the European Union directive on e-waste. This puts the onus on retailers (including online retailers) to organize an effective collection service by providing storage space for e-waste in stores and at collection points, from where they can be directed towards approved municipal waste disposal centres or recyclers (if the retailers are handling their own e-waste disposal).

Managing e-waste in households, schools[36] and offices begins by training, providing documentation through campaigns and posters that inform the public about waste sorting. Training must be made available in the appropriate national language and should bring out what participants already know and feel about the subject[37] in order target points of view at the

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[35] See Zero Waste (ZW) France. Nos outils. For example : Marine Foulon. Zéro déchet au bureau – Le Guide : 12 actions pour réduire les déchets sur son lieu de travail. 17 May 2018.

[36] It is possible to make use of educational tools, such as "photo-language" educational kits to build awareness about the link between level of affluence and approaches to managing waste, including activity books, CD-ROMs, video clips, testimonials and cartoon strips illustrating the flow of ordinary and hazardous wastes.

[37] Information to be shared should raise specific questions such as: What do we know about waste? What are the sources for what we know about waste and how we deal with it? What are the values that underpin our know-how?

individual, family, community and political level. For example, campaign illustrations dealing with sorting and waste can be distributed in schools, neighbourhoods and offices.

Eco-responsible offices must work on prevention to reduce waste generation at source, with mandatory sorting and recycling for most of the unavoidable waste. For example, cardboard packaging should be recycled, while ink cartridges and e-waste from offices must be separated and correctly disposed of, regardless of the size of the office or the volume of waste generated.

2.4 Information on e-waste drop-off locations

Increased effort to inform people of where to collect and recycle batteries, used computers and other equipment that contains toxic waste is needed. In many places, discarded mobile telephones, computers, modems, tablets and so on end up in communal landfills and unofficial dumps situated near homes, and the problem of discarded ICT equipment of local origin can be aggravated by the influx of imported waste. This waste often ends up being either buried in official landfills or dumped illegally on the roadside and in garbage dumps, where it is incinerated or simply left to decay.

Chapter 3 – E-waste value chain and management

3.1 Range of electrical and electronic equipment to be recycled

In order to facilitate treatment processes, the European Union proposes to classify WEEE into six categories under EU Directive 2012/19/EU on waste electrical and electronic equipment:

Table 1: WEEE categories according to the EU directive

Category No.	Corresponding e-waste
1	**Temperature exchange equipment** (refrigerators, freezers, equipment which automatically delivers cold products, air conditioning equipment, dehumidifying equipment, heat pumps, radiators containing oil and other temperature exchange equipment using fluids other than water for the temperature exchange, etc.)
2	**Screens, monitors, and equipment containing screens having a surface greater than 100 cm2** (screens, televisions, LCD photo frames, monitors, laptops, notebooks)
3	**Lamps** (straight fluorescent lamps, compact fluorescent lamps, fluorescent lamps, high-intensity discharge lamps, including high-pressure sodium-vapour lamps and metal halide lamps, low-pressure sodium-vapour lamps)
4	**Large equipment** (washing machines, clothes dryers, dishwashing machines, cookers, electric stoves, electric hotplates, luminaires, equipment reproducing sound or images, musical equipment (excluding pipe organs installed in churches), appliances for knitting and weaving, large computer-mainframes, large printing machines, copying equipment, large coin slot machines, large medical devices, large monitoring and control instruments, large appliances which automatically deliver products and money, photovoltaic panels)
5	**Small equipment** (vacuum cleaners, carpet sweepers, appliances for sewing, luminaires, microwaves, ventilation equipment, irons, toasters, electric knives, electric kettles, clocks and watches, electric shavers, scales, appliances for hair and body care, calculators, radio sets, video cameras, video recorders, hi-fi equipment, musical instruments, equipment reproducing sound or images, electrical and electronic toys, sports equipment, computers for biking, diving, running, rowing, etc., smoke detectors, heating regulators, thermostats, small electrical and electronic tools, small medical devices, small monitoring and control instruments, small appliances which automatically deliver products, small equipment with integrated photovoltaic panels)
6	**Small IT and telecommunication equipment** (mobile phones, GPS, pocket calculators, routers, personal computers, printers, telephones)

3.2 Organization of e-waste management system

3.2.1 Value chain

The e-waste processing chain essentially comprises the following activities: collection, transport, processing, and recycling.

a) Collection

Collections consist in gathering goods once they are no longer in a condition to be used and transferring them to processing plants. To facilitate final processing, collection may be selective according to the category of equipment, level of toxicity and type of processing required, to ensure that batches of waste are homogenous. Collection is carried out according to several methods, in particular permanent facilities and regular collection rounds.

- **Fixed or permanent collection:** This is carried out in dedicated fixed storage facilities, which tend to be set up by the organization in charge of e-waste management. Distributors may also set up similar units on their premises for the collection of end-of-life-cycle equipment. Customers drop off used equipment in these units either free of charge or for a fee, depending on the specific case or management model.
- **Regular collection:** This involves regular collection rounds within a catchment area. Waste is collected in clearly defined locations that house mobile technical storage platforms. This method also includes door-to-door collection (collection agents collect goods directly from companies or homes). E-waste collected in this way is then transported to a fixed collection point or straight to a processing centre.

b) Transportation

Transport operations involve the transfer of e-waste from regular and fixed collection points to recycling centres and must be carried out with vehicles specially equipped to transport dangerous goods. These vehicles are chartered by the local organization in charge of e-waste management.

c) Processing/recycling

According to the annual report of the e-waste register drawn up in 2016 for the French Environment and Energy Management Agency (ADEME), five types of processing are recommended. They are listed in **Table 2** in order of priority.

Table 2: Five types of processing

Name	Processing involved
Preparation for reuse	Reuse of the whole equipment after repair
Reuse in parts	Reuse of the equipment's parts or components
Recycling of material	Recycling of material from the equipment's components after manual or mechanical dismantling
Energy recovery	Incineration with energy recovery
Disposal	Disposal without recovery (landfill, incineration without energy recovery)

3.2.2 Roles

The actors involved in the e-waste management system tend to be government bodies, local authorities, producers, commercial and household consumers and civil society.

Government bodies

For most countries with an e-waste processing system, ministries and administrations responsible for environmental affairs are in charge of the implementation of e-waste collection and processing policies. They are responsible for laying the groundwork to facilitate efficient and sustainable waste management, including responsibility for:

- developing, promoting and monitoring the legal and regulatory framework for the management of e-waste and protection of the environment;
- monitoring the implementation of existing regulations;
- establishing an appropriate financing mechanism for the system.

Producers

In the context of e-waste management, a producer in the European Union is defined as any natural or legal person, established in a Member State, who manufactures or markets or resells EEE under his own name or trademark; places on the market of that Member State, on a professional basis, EEE from a third country or from another Member State; or sells EEE by means of distance communication directly to private households or to users other than private households in a Member State, and is established in another Member State or in a third country.[38]

It is important to define what a producer is because an efficiently functioning e-waste management system should be accompanied by an inventory of the names and contact information of all producer that are selling e-waste in a country. In the absence of any national registry of EEE producers, there is no mechanism to hold producers accountable for end-of-life management of EEE. Under a system of extended producer responsibility (EPR), these producers would be accountable for the management of EEE. An introduction to EPR can be found in **Chapter 1**.

Consumers

Consumers are normally in charge of separating waste at source and, depending on the financing model of the e-waste management system, they may also partially bear the costs either when purchasing new EEE or when disposing of it.

The role of the consumer is extremely important in the e-waste management system, as it is consumers who are in charge of deciding on the purchase and disposal of e-waste and who determine the use and the lifespan of equipment.

Consumers generally fall into two categories, for which different waste-management strategies may be required for the purposes of awareness raising and waste collection:

- households and small businesses;
- bulk consumers, such as government agencies and large private businesses.

[38] European Union. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on WEEE. Article 3(f).

Households and small businesses are the principal producers of electrical waste. They are responsible for returning end-of-life-cycle equipment to distributors or specific waste-collection facilities. They should be aware of the harmful effects of electrical equipment on health and the environment. They are also directly involved in the financing of the WEEE management system, thanks to the tax paid on the purchase of new equipment or the contribution (eco-participation) payable on the recovery of used equipment.

Recyclers

A recycler can be defined as the natural or legal person responsible for ensuring that the requirements of a regulation, as regards the recycling process, are met within the business that is under their control. The e-waste recycling process can be defined as "any recovery operation by which waste materials are reprocessed into products or materials whether for original or other purposes."[39]

Recycling organizations play an essential role in the management of WEEE and they also engage in collection, transportation and storage activities. Authorized recyclers should be handling e-waste, but there may also be informal recycling activities taking place in a country, which should be addressed in national policy.

Governments

Government refers to all relevant ministries and departments, at the national and local levels, with a role or responsibility in governing the e-waste value chain.

In the e-waste management system, the government should be involved in licensing and enforcement, and the control of transboundary movements. National and local government should oversee the constitutional and legal framework, environmental permits and roles and responsibilities of other actors in the e-waste value chain, including financial instruments, environmental impact assessments and municipal solid waste management and standards.

Any creation of a producer responsibility organization (as described in **Chapter 1**) should be carried out under the guidance of the government.

Local authorities

Local authorities should assume responsibility for the collection and processing of municipal waste and for developing and implementing local waste-management strategies or implementing national strategy. They may be responsible for outsourcing waste collection and processing services. In certain management systems, local communes set up specific collection sites for e-waste and take responsibility for the transport of waste to processing facilities.

Producers/distributors of electrical and electronic equipment

These include manufacturers, importers, wholesalers and retailers of EEE. They play a major role in e-waste collection and processing. In certain cases, producers and distributors are wholly responsible for the management system and are obliged to take back used equipment from

[39] European Union. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance). Article 3(17).

end users (households and companies). This can involve directly accepting goods at their respective facilities through their own collection infrastructure. Sometimes, e-waste is only accepted at the time of purchase of a new piece of equipment, known as one-for-one recovery. It is then reconditioned using their own infrastructure or is integrated into the local processing system. EEE distributors also play a central role in the financing of the recovery system. They are responsible for collecting fees for the processing of used equipment and transferring the money to the recycling organization. These fees are payable either on the purchase of new equipment or on the return of used equipment.

3.3 Overview of the situation in some countries in the Africa region

According to the Global E-waste Monitor 2020 the Africa region generated 2.9 Mt of e-waste in 2019.[40]

In the Africa region, e-waste tends to be managed by informal-sector operators with little involvement from the public sector in either organization or financing of the management systems.

There are initiatives in place, but their impact remains limited. Regional organizations such as the Economic Community of West African States (ECOWAS) are working to establish a framework for more efficient WEEE management, involving the 15 member countries of ECOWAS.[41]

In Senegal, there are private dismantling facilities which receive equipment from private companies, such as the National Telecommunications Company (Sonatel), and public authorities. Through the State Information Technology Agency (ADIE), Senegal is reviewing a decree to supplement Law No. 2001-01 of 15 January 2001 on the Environment Code and implementing Decree No. 2001-282 of 12 April 2001 in order better to provide for WEEE collection and processing.

Benin has attempted to reinforce its legal framework so that it can better manage the flow of devices entering the country.[42] Under the E-waste Africa project,[43] national e-waste management strategies are starting to take shape in Côte d'Ivoire, Ghana and Nigeria, with the latter having passed a dedicated EEE regulation in 2011.

40 See ISWA. The Global E-Waste Monitor 2020. *ISWA News*, 2 July 2020.
41 West Africa Telecommunications Regulators Assembly (WATRA). Validation Workshop of the Study on the Management of Electronic Waste in West Africa, Dakar, 17-18 June 2019.
42 Cheikh Diop and Ramata Thioune. Les déchêts électroniques et informatiques en Afrique: Défis et opportunités pour un développement durable au Bénin, au Mali et au Sénégal. Edition Khartala and International Development Research Centre (Canada), 2014.
43 See UNEP. The Basel Convention. Enhancing Parties capacities for the environmentally sound management of e-wastes through the enhanced regional delivery: e-waste activities in Africa.

Table 3: Overview of legislation and initiatives on e-waste[44]

Country	Legislation on e-waste	E-waste initiatives
E-waste collection centre		
Cameroon	Draft regulation	Has an EPR scheme
Egypt		Has three main recycling companies
Ghana	E-waste law	Has put in place an advanced recycling eco fee Guidelines on e-waste recycling
Kenya	Draft regulation	National Steering Committee on e-waste management Has a recycling facility
Madagascar		Draft regulation
Malawi		E-waste strategy
Morocco		National e-waste strategy E-waste project
Nigeria	Draft regulation	Has in place a guide for importation of used EEE Manages illegal trade of e-waste
Rwanda	E-waste policy	National Steering Committee on e-waste management E-waste recycling facility
South Africa	E-waste law	E-waste strategy
Tanzania		National Steering Committee on e-waste management
Tunisia	E-waste management under the general legislation on waste control, use and disposal	Has conducted an assessment on e-waste data in the country
Uganda	New environmental law 2019 that has a specific section on e-waste (separate from hazardous waste) E-waste policy E-waste guidelines	E-waste strategy, E-waste guidelines National Steering Committee on e-waste management, Has conducted a study on end-of-life management of ICT equipment
Zambia		Draft regulation

[44] E-Waste Guidelines for African Telecommunications Union Member States. Overview, Guidelines and Indicators, pp. 20-21

Funding

Support is being provided on a technical or financial basis, such as:[45]

- ITU in Malawi (assistance in the development of the national strategy)
- GIZ (German cooperation) is helping East African countries to develop a regional strategy
- Italy is supporting Egypt in a waste-management programme under the supervision of UNDP
- UNDP is supporting Uganda in developing its national strategy.

3.4 Case studies on e-waste

Burundi has drawn up regulations on the ecological management of WEEE.[46] It has established a coordination committee, developed a regulatory framework, and holds workshops for WEEE management. In cooperation with the private sector, training is conducted on awareness raising, collection and separation.[47]

India relies on an ICT in cleanliness mission to minimize harmful effects of e-waste, solid wastes and ground pollutants.[48] As part of its e-waste management strategy and circular-economy vision, large amounts of precious metals are collected by recycling mobile phones. India has also created employment through recycling. In Bangalore, the operation of unauthorized recyclers has been banned and electronic waste is monitored, and these efforts have been successful.[49]

The Russian Federation has set out a new list of banned substances and stipulated final disposal responsibilities for producers and importers in its current legislation in the field of WEEE management.[50]

The African Civil Society on the Information Society (ACSIS) sets out a number of challenges and recommendations for disposal of e-waste in the Africa region. It has established e-waste treatment as an industry, and provides information, tools for treatment and training in accordance with international standards.[51]

Brazil has established a Federal Law on Solid Waste and WEEE.[52]

Sri Lanka, as part of a series of e-waste management initiatives, has identified the need for the rapid development of a sustainable policy framework for the disposal or reuse of e-waste, recognizing that, in the near future, the large amount of e-waste generated by outdated telecommunication equipment, such as mobile phones, landline phones, personal computers, broadcast equipment and peripherals, could cause environmental, social and economic problems, and that a sustainable policy framework needs to be developed quickly in order to dispose of or recycle waste.[53]

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45 E-Waste Guidelines for African Telecommunications Union Member States. Overview, Guidelines and Indicators, p. 22
46 ITU-D SG2 Document 2/48 from Burundi
47 ITU-D SG2 Document 2/143 from Burundi
48 ITU-D SG2 Document 2/72(Rev.1) from India
49 ITU-D SG2 Document 2/197 from India
50 ITU-D SG2 Document SG2RGQ/52 from the Russian Federation
51 ITU-D SG2 Document SG2RGQ/51 from the African Civil Society for the Information Society (ACSIS).
52 ITU-D SG2 Document SG2RGQ/37 from Brazil
53 ITU-D SG2 Document SG2RGQ/109 from Sri Lanka

Cameroon recognizes the importance of introducing specific strategies for the collection and processing of WEEE; the complexities of the telecommunication environment; and the increases in the use of equipment to access infrastructure and services and in electromagnetic radiation present in the environment. Cameroon has a legal and regulatory framework aimed at reducing the adverse effects of e-waste.[54]

In the Russian Federation,[55] the communication operator Tele2, one of the country's largest mobile operators, launched an environmental project to draw customers' attention to the problem of recycling electronic waste and to encourage its proper disposal. Tele2 opened 68 collection points for unwanted devices in 11 Russian cities. All devices received would be sent for recycling to a leading company specializing in the disposal of electronic equipment. Also, the communication operator MTS has been implementing a strategy of energy saving and energy efficiency, focused on limiting the growth and reducing the consumption of electric power.

The ITU Association of Japan[56] reports on methods to recover lead-acid batteries and how this battery regeneration technology can contribute to telecommunications/ICTs in rural and remote areas. The proposed technology can be useful in prolonging the lifetime of lead-acid batteries used for telecommunication/ICT or other facilities in developing countries, in particular in rural and remote areas. The technology will contribute to improving the environment and bridging the digital divide.

[54] ITU-D SG2 Document SG2RGQ/119 from Cameroon
[55] ITU-D SG2 Document 2/394 from Russian Federation
[56] ITU-D SG2 Document SG2RGQ/247 from the ITU Association of Japan (Japan)

Chapter 4 – Frontier technologies and climate-change mitigation

4.1 Background

Climate change is one of the most serious challenges being faced by the global community. The unequivocal and unprecedented temperature fluctuation and the upward trend in the Earth's average temperature[57] has become a constant in most regions, manifested in the melting of glaciers, rising sea levels, floods and submerging coastlines and changing rain patterns and distribution, affecting the biomes, cropping patterns and economies everywhere. According to the World Meteorological Organization (WMO), other indicators include:

- warming of oceans and acidification of sea water;
- increases in atmospheric carbon dioxide, which is currently at an all-time high;
- changes in Arctic and Antarctic sea ice, with breakages in major glaciers;
- fires over large geographical areas; and
- destruction of biodiversity.

According to WMO State of the Global Climate reports, 2015 to 2019 was the warmest five-year period on record, and 2010-2019 the warmest decade on record. Since the 1980s, each successive decade has been warmer than any preceding decade since 1850.[58]

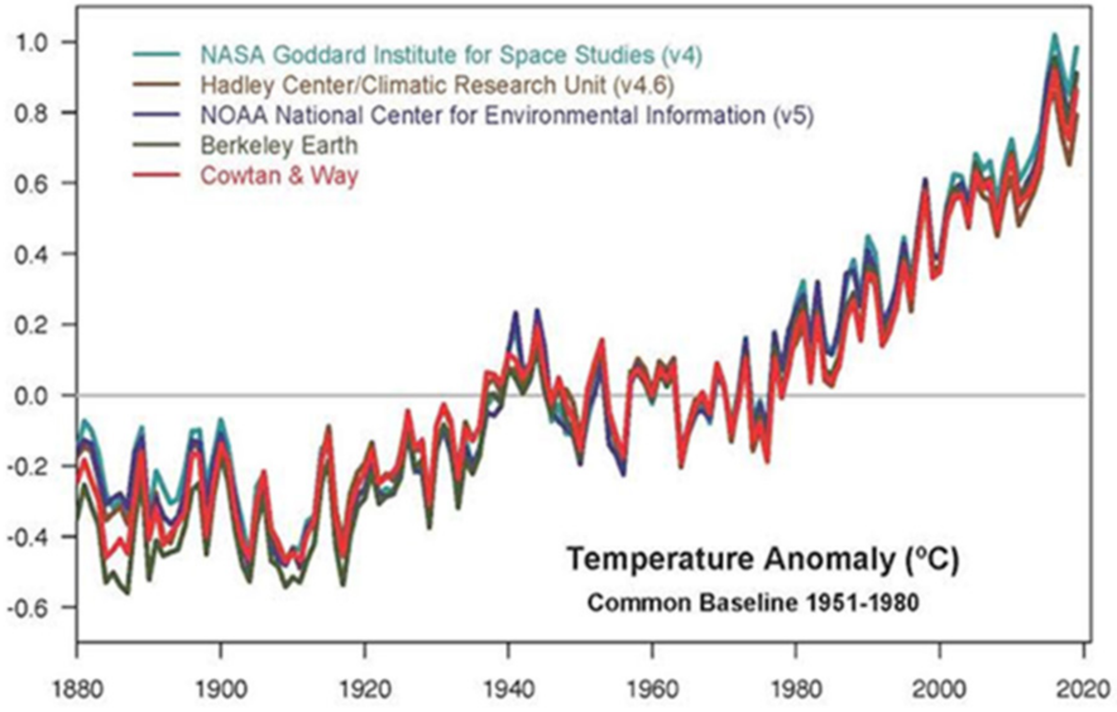
Since the pre-industrial era, between 1880 and 1900, there has been a 2°C temperature rise, which is a massive increase in heat accumulated by the atmosphere. The 2019 Global Climate Summary[59] published by the United States National Oceanic and Atmospheric Administration (NOAA), reports that on average the combined ocean and land temperature has risen by a total of 0.07°C (0.13°F) for each decade since the year 1880; this rise in temperature has almost doubled (0.18°C/0.32°F) since 1981. The report projects that by the year 2020, irrespective of carbon dioxide emissions, the world would be warmer by 0.5°C (0.9°F) compared to the 1986-2005 average temperature. However, it is predicted that this is a temporary phenomenon because of the thermal inertia of the oceans that are absorbing massive amounts of heat from the atmosphere, and by the next decade this imbalance of trapped heat will start to be felt, and if left unchecked will pave way for much higher global temperatures by the end of the century. **Figure 5** shows how temperatures are changing over time, compared to a baseline average from 1951 to 1980, as recorded by five different entities. The records show rapid warming in the past few decades, and that the past decade has been the warmest.

[57] WMO, based on real-time analysis of global temperature readings annually and comparison with historical data, further confirmed a consistent rise in global temperatures. Similar statistical analysis has been made in research conducted by the US National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information. According to the Copernicus Atmospheric Monitoring Service, the uneven distribution of global warming is seen by rapid warming of Western Siberia and fires in the Arctic, while Alaska is showing cooler temperatures than before.

[58] WMO. Multi-agency report highlights increasing signs and impacts of climate change in atmosphere, land and oceans. *Press release*. New York/Geneva, 10 March 2020.

[59] NOAA. National Center for Environmental Information. State of the Climate: Global Climate Report - Annual 2019. Published online, January 2020.

Figure 5: Global temperature anomalies (1880 to 2019)



Source: NASA[60]

4.1.1 Examples of impacts of climate change in the world

January 2020 was the warmest January on record, with milder winters in many parts of the northern hemisphere, ice melting in Antarctica and sea levels rising; and large-scale fires in Australia and the Americas region have caused a rise in carbon dioxide levels. In Australia, the 2018-2019 summer was the hottest ever recorded, reaching a peak of 41.9°C on 18 December, and in 2019 Australia suffered seven of the hottest days on record. Brazil has faced similar extreme rises in temperature and accompanying catastrophic wildfires. Many counties in Europe have experienced high temperatures, and wildfires have plagued Siberia, Alaska, the Arctic, South America, Indonesia and neighbouring countries.

4.1.2 Events leading towards climate change

The WMO Statement on the State of the Global Climate in 2019, released in March 2020, provided information for policy-makers on the need for climate action.[61] This publication compiled data (using frontier technologies such as Earth observation, big data and other ICTs) from various agencies working towards climate action and focused on the possible repercussions of climate change on the world, which include adverse impact on health and economies, displacement and reduced food security. According to United Nations Secretary-General António Guterres, the world has not yet met the Paris Agreement target of a 1.5°C or 2°C reduction in global temperatures, with the WMO Secretary-General indicating that the coming five years will record new highs in global temperatures.

60 National Aeronautics and Space Administration (NASA). NASA, NOAA Analyses Reveal 2019 Second Warmest Year on Record. Release 20-003, 15 January 2020.

61 WMO. Statement on the State of the Global Climate in 2019. WMO-No. 1248, 2020.

The World Weather Attribution assessed the quantitative contribution of climate change to the recent bushfires in Australia and concluded that global warming increases the incidence of bushfires by 30 per cent.[62]

4.1.3 Agencies involved in climate-change mitigation

UN and climate change

The United Nations Environment Programme (UNEP)[63] advocates a global environmental agenda while promoting implementation of environmental aspects of sustainable development within the United Nations system.

ITU and climate change

The International Telecommunication Union (ITU)[64] assists Member States in developing national policies and capacity building required to promote sustainable development goals with proper use of ICT applications, services and networks.

ITU promulgates pertinent information through tools, data and training materials for knowledge sharing, policy-making and focused actions towards climate-change mitigation.

It supports the Global e-Sustainability Initiative (GeSI) alongside the United Nations in a global partnership of key stakeholders in the ICT sector to promote ICTs for sustainable development. ITU assists members to predict and be prepared for the impact of environmental disasters and plan disaster relief by utilizing earth observation, big data and emergency telecommunications.

WMO

The World Meteorological Organization (WMO)[65] has an extensive network of partners. WMO focuses on documenting climate events, with inputs from Earth observation, national metrological and hydrological services, UN agencies and scientific communities on the impact of weather on different human activities, such as marine and land ecosystems, human health, agriculture and food security, socio-economic development, migration and human displacement. WMO monitors climate change at the global level, providing WMO Member States with accurate, reliable, evidence-based information for informed decision-making towards climate-change mitigation, risk assessment, disaster management and increased efforts towards energy efficiency, helping countries to transition towards a carbon-neutral economy.

Paris Agreement

The Paris Agreement,[66] which is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC), aims to "limit global warming to well below 2°C, preferably to 1.5°C, compared to pre-industrial levels". As of 2020, all UNFCCC member countries had signed the agreement, with 190 countries becoming a party to it.

62 World Weather Attribution (WWA). Analyses - Heatwave. Attribution of the Australian bushfire risk to anthropogenic climate change. 10 January 2020.
63 UNEP: https://www.unenvironment.org
64 ITU. ITU Activities. ITU work on the thematic area of environment, climate change and e-waste.
65 WMO: https://public.wmo.int
66 United Nations. Climate Change. The Paris Agreement.

UN Climate Change Conference (COP25)[67]

The United Nations Framework Convention on Climate Change (UNFCCC) is supported by WMO. Each year, updated scientific data are provided to governments by UNFCCC, including climate and greenhouse gas status. COP25 will follow the implementation of the Paris Agreement to keep global mean temperatures below a 2°C rise in pre-industrial levels and strive towards limiting the temperature increase to 1.5°C.

4.2 New technologies, systems and applications to monitor the climate and reduce its impact

To tackle climate change, countries will need, among other things, to use the most powerful ICT tools to address issues related to society and ecology, and to support actions and provide solutions to mitigate real-world problems. According to UNEP, the world is at a pivotal moment in environmental history when these technologies can fundamentally change the trajectory of, and underpin, a sustainable future.[68]

Frontier technologies such as artificial intelligence (AI), big data, cloud computing and the Internet of Things (IoT) have the potential to make society inclusive, safe, resilient and sustainable. The use of AI to learn and solve problems will enable better data integration, analysis and interpretation. AI decisions and outputs can improve prediction of extreme events such as hurricanes and weather on a hyper-local level using large-scale models. It can also help to reconstruct past climate conditions using, for example, geological data or records of previous weather stored in the polar ice fields.

Big data uses large, complex volumes of data that are difficult or impossible to process using traditional methods. Big data can be used to generate insights that lead to better decisions and strategic business moves.

Cloud computing is a method of running application software and storing related data in a central computer system, providing customers or other users access to them through the Internet. This includes software as a service (SaaS), whereby computing services and resources, such as servers, storage, databases, networking, analytics and intelligence are shared rather than having local servers or personal devices to handle them.

IoT refers to the "global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies", according to Recommendation ITU-T Y.2060/Y.4000.[69] IoT encompasses machine-to-machine (M2M) and machine-to-people (M2P) direct communication, and applied science related to ambient intelligence and smart environments.[70]

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67 United Nations. Climate Change. UN Climate Change Conference (COP25) - December 2019.

68 David Jensen. Crisis Management Branch, UNEP. Harnessing the power of big data and frontier technologies for climate action. *ITU-D Workshop on Frontier ICTs for Climate Action*, Geneva, 15 October 2019.

69 ITU. Recommendation ITU-T Y.4000/Y.2060 (06/2012). Overview of the Internet of Things.

70 ITU. Frontier technologies to protect the environment and tackle climate change. April 2020.

Other technology trends may also help climate action:[71]

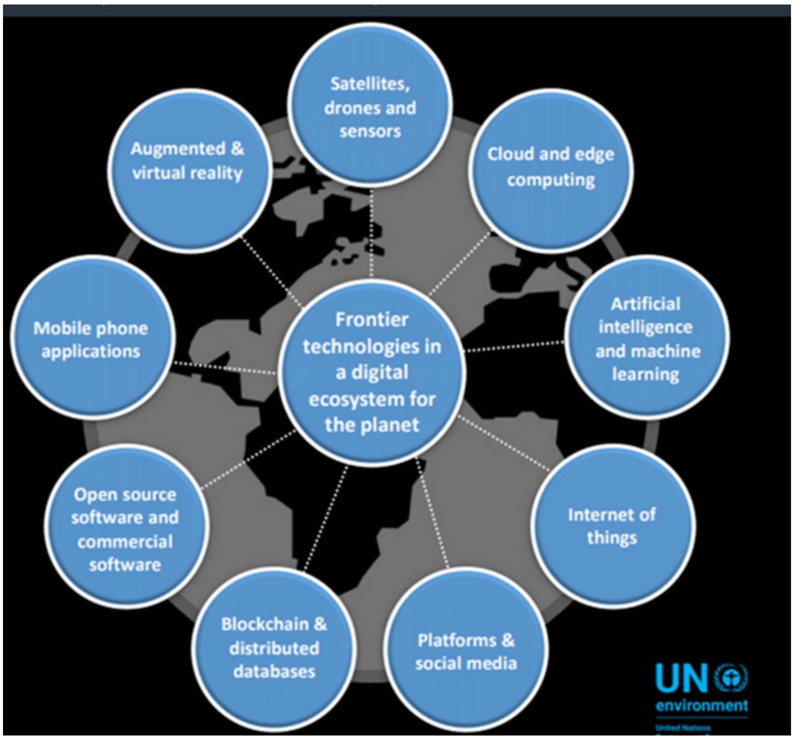
- *Augmented and virtual reality* (AR/VR) merges the physical and virtual worlds, and by stacking elements of virtual reality onto real-life scenarios, AR/VR can for example enable people to have a virtual experience of environmental and climate-related issues.
- *Edge computing* is similar to cloud computing but brings computing and data storage closer to the originating data source to improve response times and reduce the volume of traffic over the wider network.
- *Blockchain* and *distributed databases* can help address the climate crisis by, for example, improving accountability, transparency and efficiency of carbon stocktaking for low-carbon projects, carbon offset trading in carbon markets, peer-to-peer energy trading in decentralized clean energy markets, and climate finance in terms of old and new business practices.[72]
- *Machine learning*, a discipline of AI, involves the implementation of computer software that can learn independently.
- *Platforms* and *social media*, which can foster conversations on climate-change mitigation and adaptation engagement and increase awareness.
- *Open-source software* (available to users to change, modify and distribute) and *commercial software* can be embedded for example in devices, IoT gateways, edge nodes and measuring and monitoring instrumentation.
- *Mobile-phone applications*, which make information available on climate-change risk and can replace many human activities that wreak significant damage on environmental systems.
- The use of *satellites* combined with *drones* and *sensors* can collect information about our planet.

As illustrated in **Figure 6**, the combination of emerging technologies can transform the way we monitor the Earth and boost climate resilience.

[71] The definitions given here represent a compilation from many expert sources, online dictionaries and encyclopedias, such as the Building Block(chain)s for a Better Planet report from the World Economic Forum (WEF), Encyclopaedia Britannica, Cambridge Dictionary, Wikipedia and ITU workshops.

[72] UNEP. How Blockchain Technology Could Boost Climate Action. UNEP news article. 1 June 2017.

Figure 6: Technology trends



Source: David Jensen (UNEP, 2019)[73]

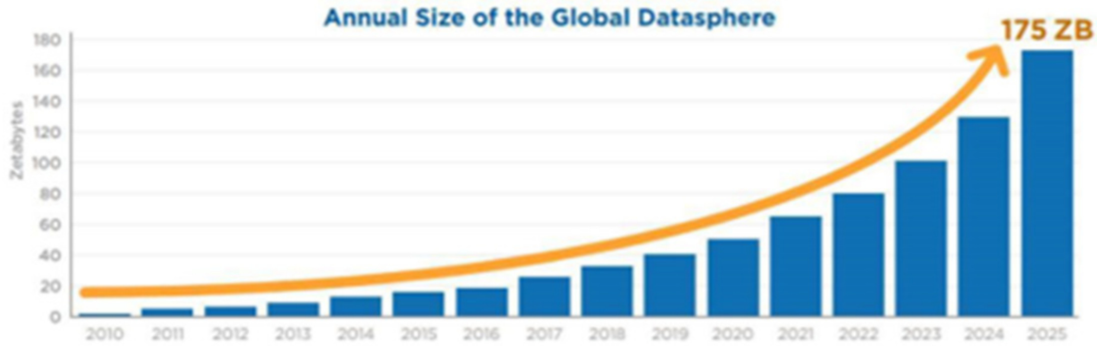
The aim of the following sections is to better explain big data and AI and to demonstrate how they are valuable aids for achieving Sustainable Development Goals 11, 12 and 13, set by UNEP.

4.2.1 Big data

Digital technology and big data are now in common use, although many stakeholders are still thinking about how to implement them in new policies, business models and products to capture their value. Data is the bedrock of the digital economy. Climate change and ecological measurement is the ultimate big-data challenge. Generally, big data refers to extremely large datasets that computationally reveal patterns, trends and associations, especially relating to human behaviour and interactions. **Figure 7** shows the rise in the volume of digital data from 2010 to 2025, when it will reach 175 zettabytes (ZB).

[73] Jillian Campbell and David Jensen (UNEP). The promise and peril of a digital ecosystem for the planet. 11 September 2019.

Figure 7: Annual size of the global datasphere



Source: IDC[74]

One zettabyte is equal to 10^{12} gigabytes (GB). 175 zettabytes in a digital video disk (DVD) would circle the Earth 222 times and the amount of data generated by human history is about 0.005 ZB!

The fourth version of the Internet Protocol (IPv4) was exhausted by 2011, having provided 4 294 967 296 different IP addresses. The sixth version (IPv6) is capable of providing 340 282 366 920 938 463 463 374 607 431 768 211 456 IP addresses, almost one address for every cell in the human body![75]

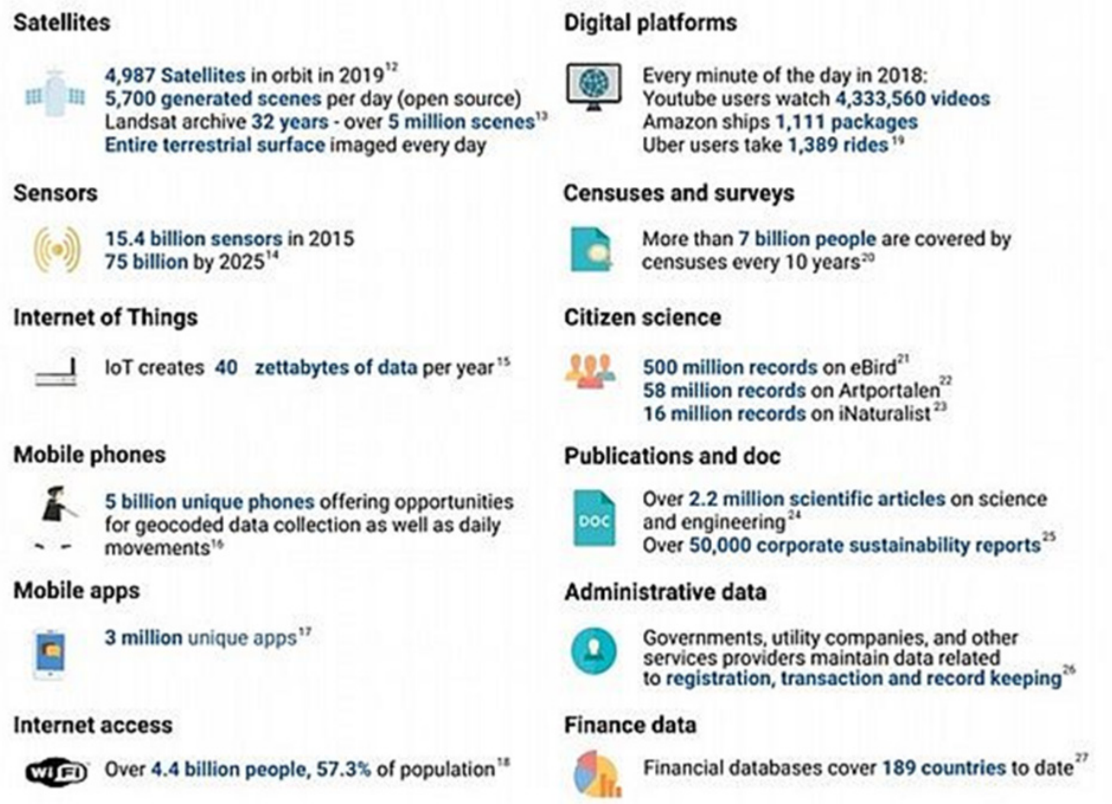
Big data, for example from social networks, systems and sensors, is characterized by high volume, velocity, variety and veracity. It is also an organic by-product of IoT due to the ability of machines to generate, process and analyse large volumes of data at high speeds.[76] Big-data sources include applications such as pollution and weather sensors, health, satellites, food-security measures, geolocation and traffic sources. **Figure 8** details some facts and numbers.

[74] International Data Corporation (IDC). IDC White Paper. Data Age 2025: The Digitization of the World from Edge to Core, updated May 2020

[75] David Jensen. Crisis Management Branch, UNEP. Harnessing the power of big data and frontier technologies for climate action. *ITU-D Workshop on Frontier ICTs for Climate Action*, Geneva, 15 October 2019

[76] ITU. ITU-T and climate change. Frontier technologies, 2020

Figure 8: Big-data sources

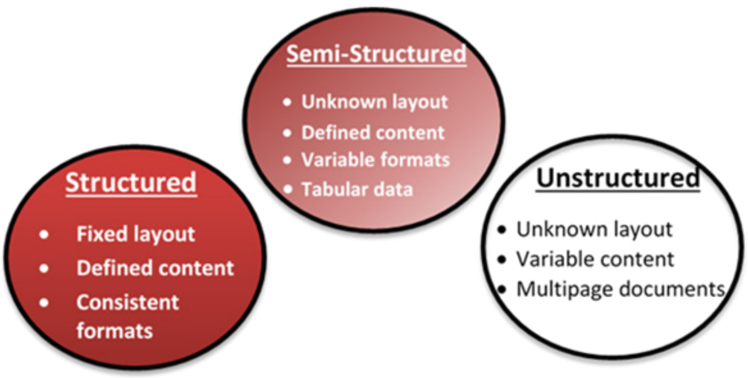


Source: David Jensen (UNEP, 2019)[77]

Figure 9 shows the data types inside the big-data paradigm:

- *structured*: Deeply organized information that can be promptly and seamlessly stored and accessed from a database by search engines, for example, a data table with the daily historical weather for a city containing temperature, precipitation, wind.
- *semi-structured*: Textual data files with a discernible pattern that contain vital information or tags to segregate the data into various hierarchies, for example, extensible mark-up language (XML).
- *unstructured*: Data that have no specific form and are usually stored as different types of files, e.g. e-mail, text documents, PDF archives, images and video.

Figure 9: Big-data data types



[77] David Jensen. Crisis Management Branch, UNEP. Op. cit.

The challenge is how to make usable data, for example in the form of graphs, tables and statistics, from a range of many data sources.

4.2.2 Artificial intelligence

Artificial intelligence (AI) already plays a big part in people's lives. The term AI is often used in developing system projects that reflect human intellectual processes, such as the ability to reason, discover meaning, generalize or learn from past experiences. Branches within this field include machine learning (ML), artificial neural networks (ANN) and data mining, and many are used in prediction and pattern recognition.

With the tools to structure and analyse massive amounts of data, the availability of computing resources, low-cost graphical processing units (GPU) and cloud computing, AI has the potential to face the challenges of climate action and realize the opportunities of green ICTs.

AI will help to solve many real-life dilemmas such as mitigation and management of climate-change related risks, food security, energy efficiency, solar geoengineering, better monitoring of deforestation, greener transportation and better climate predictions.

The efficacy of AI, which requires large amounts of computing power and energy, relies on effective integration into other technologies and the decarbonization of the energy system. This will be more important as studies show that ML processes alone can emit more than 626 000 pounds of carbon dioxide, approximately equivalent to five times the lifetime emissions of an average car.[78]

4.2.3 Machine learning[79]

The basic concepts of the wide variety of ML techniques are introduced briefly in this section, including examples of use in the ICT sector to accelerate progress towards the United Nations Sustainable Development Goals.

Machine "learning" often refers to obtaining general models from a set of examples and segregating relevant information or typical standards from datasets. Combining ML with discrete use cases of the sensors from an IoT network improves the accuracy of models, for example reducing uncertainties in climate forecasts.

The three major learning paradigms are:

- Supervised learning model: Learns with the help of the right answer (regression and classification problems).
- Unsupervised learning model: Learns the structure, there is no right answer (clustering and association problems).
- Reinforced learning model: Learns actions that lead to some reward (optimal control problems, robotics and game theory).

ML algorithm performance depends on the abundant availability of structured and unstructured data; high-quality data, connectivity, computational power, statistical analysis and expertise are also necessary.

[78] ITU. ITU-T and climate change. Op. cit.
[79] David Rolnick et al. ITU-T and climate change. Frontier technologies, 2020. Tackling Climate Change with Machine Learning. June 2019; and Wikipedia: Machine learning and Reinforcement learning.

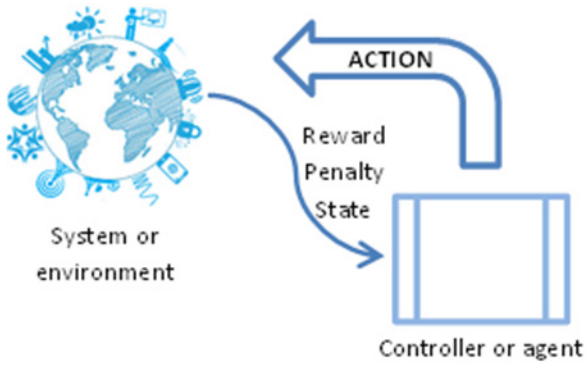
Random decision forest methods are used to solve a multitude of classification and regression problems. For example, with regard to SDG 2 (Zero hunger) and SDG 12 (Responsible consumption and production), operational frameworks based on random forest methods can carry out cropland mapping.

Temporal and spatial clustering for parking prediction services is a strategy that helps to deliver SDG 11 (Sustainable cities and communities), since car-park availability has become an issue in urban areas. In several cities of the world, systems have emerged that simplify the search for free parking spaces and improving road-traffic efficiency, especially when combined with IoT data.

Reinforcement learning (RL) is an area of increasing interest to the robotics research community for intelligent manufacturing systems and flexible automation, such as autonomous disassembly technologies, useful for the management of e-waste. There are connections to SDG 9 (Industry, innovation and infrastructures) and SDG 12 (Responsible consumption and production).

RL is a computational system that learns how to reach a goal. The methods are Q learning and the Markov decision process (MDP). In **Figure 10**, the controller or agent performs an action, which affects the system or environment. Thus, it receives a reward based on the executed action and how it affected the environment/system. Throughout the training, the agent/controller tries to maximize the rewards.

Figure 10: Reinforcement learning loop



Source: ITU

4.2.4 Artificial neural networks[80]

An artificial neural network (ANN) is a computational model inspired by the workings of a biological brain. ANN is a framework for deep learning (DL) or multi-layer neural network that progressively extracts higher level features from raw input. DL allows the application of learning processes with multiple layers of abstraction by taking advantage of high-speed computational resources. It has dramatically improved the results provided by machine learning.

Neural networks learn by processing examples that contain known input sets and results. The difference in the state of the network before and after processing the example (formed by probability-weighted associations) is the learning process. After a sufficient number of examples, the network becomes capable of predicting results from inputs, using the associations built from the example set.

[80] David et al. Op. cit.

Certain types of neural networks, called general adversarial networks, can create new content based on probabilistic models given the right set of training data, for example how the exterior of a given house will look when affected by flooding. Neural networks can also resolve complicated and small-scale atmospheric processes, for example to reduce uncertainties inherent in current climate models, including convective cloud formation to estimate real-time precipitation, which is useful in drought management.

4.2.5 Data mining[81]

Data-mining methods of machine learning and mathematical analysis extract knowledge to derive patterns and trends from large datasets in order to identify relevant information and transform it into a comprehensible structure for further use. These patterns cannot be discovered easily by traditional data exploration because the relationships are too complex or there is too much data. For example, it is usual to perform data mining on terabytes of information. Data mining may be useful for the attainment of SDG 13 (Climate action) and SDG 2 (Zero hunger) when used to address food security and production.

4.3 Country case studies on new technologies for climate-change monitoring

4.3.1 Mitigation activities against the impact of climate change (India)

India carried out activities to mitigate the impact of climate change by deploying new ICT technologies.[82] The e-Arik (e-agriculture) project used ICT solutions to mitigate climate change in the Arunachal Pradesh region by promoting climate-friendly agricultural practices. This project has contributed significantly to food security, economic growth and living standards in the region.

ICTs played a role in reducing the impact of cyclone "Fani" utilizing, for example, satellite-image analysis and advanced weather forecasting to predict the cyclone path and the precise extent, depth, and duration of flooding in the lowlands, which minimized loss of life by sheltering a million people before the cyclone hit.

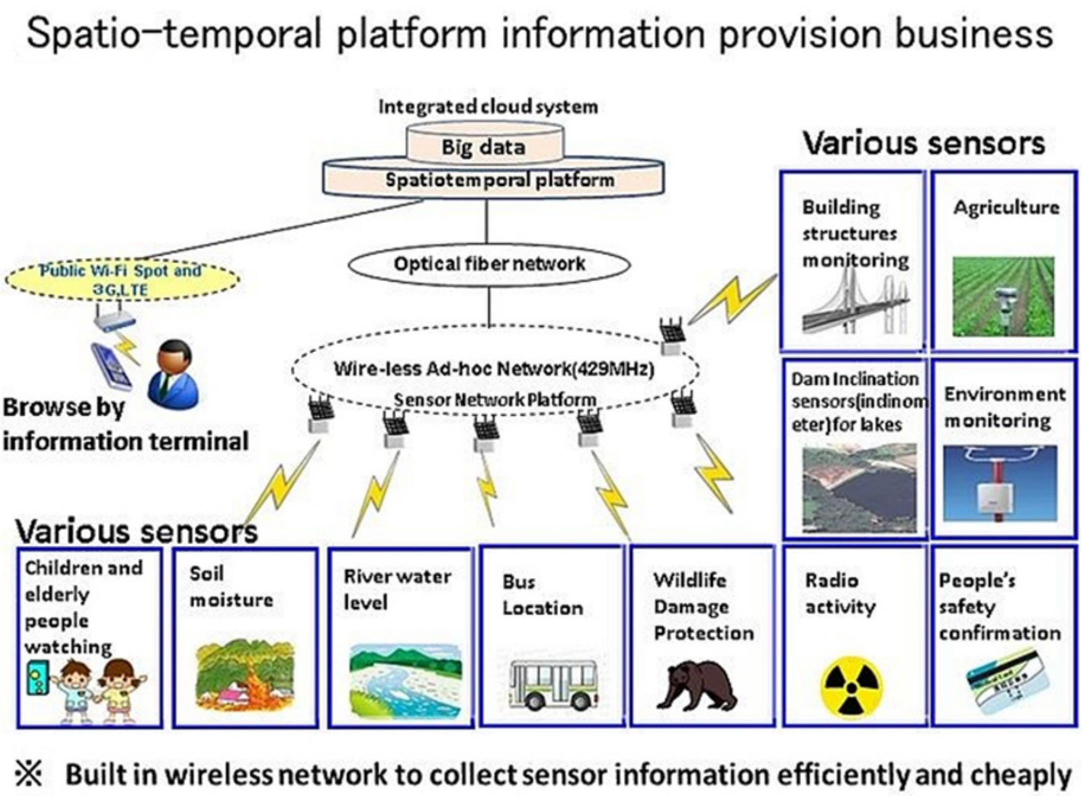
4.3.2 Environmental information sensor networks and other case studies in Shiojiri City (Japan)

In Japan, the population is exposed to the threat of floods, large-scale typhoons caused by climate change, earthquakes and virus pandemics. Shiojiri City, which has about 70 000 inhabitants, has been implementing the smart-society concept by creating environmental information sensor networks (see **Figure 11**) and systems using drones and AI. Empowerment of local communities contributes to the sustainability of local industry through the development of IoT sensors and related application software. In addition, the eco-friendly renewable energy biomass power generation system, which has smart functions and is carbon neutral, is linked to the community energy grid to supply almost all households and ICT networks in the city.

81 SIGKDD. Data Mining Curriculum: A Proposal. 2020; and Wikipedia: Data mining.
82 ITU-D SG2 Document SG2RGQ/132 from India

This plant will contribute to the local forestry and lumbering industries and to the carbon sink of greenhouse gas emissions.[83]

Figure 11: Shiojiri environmental information data-collection platform and its IoT sensor network



Source: Japan

Background

In 2000, the Shiojiri municipality started to build the 130 km autonomous optical fibre network, which now connects all public facilities in the city. The network is interconnected with upper layer service providers. In addition, the low-power wireless area network deploying 429 MHz frequency spectrum was built with ad-hoc network configuration and is operating with 640 distributed wireless repeater stations and self-sustained IoT sensors. As a result, the entire Shiojiri City has become a sustainable and affordable wireless communication area operated by local government.

Shiojiri municipality has promoted the development of ICT-related devices and application software by local businesses and academia (the university, college and technical high school) and has invested in a network of IoT sensors to automatically collect and exchange local environmental data, as well as a biomass power plant to supply low-cost, eco-friendly and carbon-neutral power to the region's 67 000 population.

[83] ITU-D SG2 Document SG2RGQ/28SG2RGQ/28+Annex from Japan

Case studies

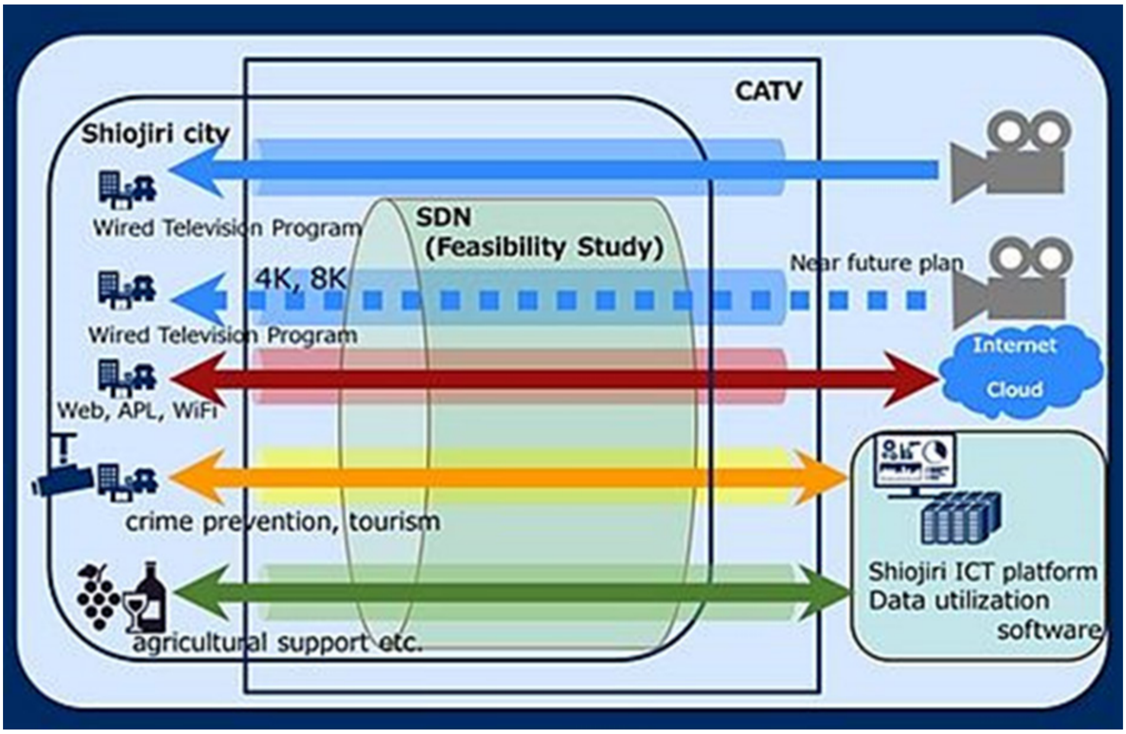
a) Data such as temperature, humidity and solar radiation are used to reduce the amount of agricultural chemicals for pest control, which has lowered costs and reduced the environmental impact of pesticides.

b) The conventional method of predicting mudslides or landslides relied upon rainfall and duration based on expert knowledge. Warnings are now sent out automatically when IoT sensors detect threshold soil moisture levels.

c) It has been difficult to predict severe frost in the past. However, with the implementation of IoT sensor networks that measure and calculate temperature and humidity, frost warnings are issued to enable farmers to protect crops from frost damage.[84]

d) A feasibility study proved that by providing services closely tied to local residents and communities makes it easier to sustain important information communication infrastructure for rural areas. Software-defined networking (SDN) technology makes services visible, so providers can better understand how services are being used and can provide more appropriate content and service quality. SDN slicing technology secures real-time traffic volume control and service quality using a common network infrastructure (see **Figure 12**), resulting in reduced infrastructure and operating costs.

Figure 12: Case study of CATV information communication infrastructure with SDN

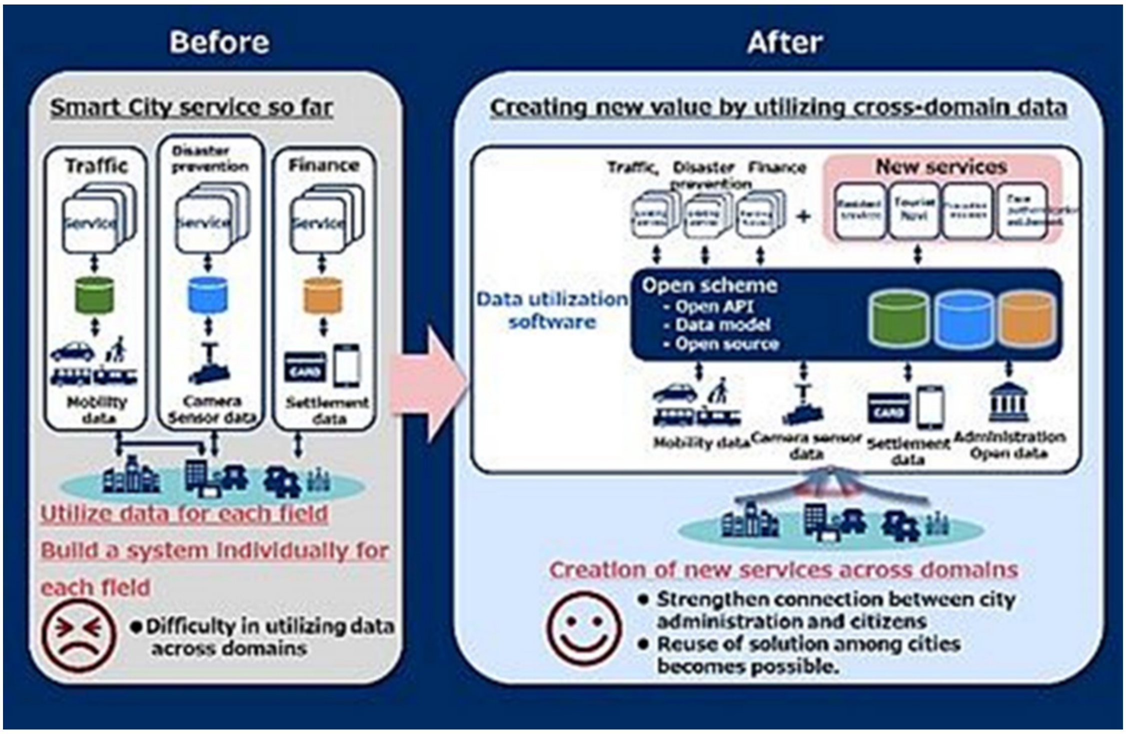


Source: NEC Corporation, Japan.

e) Shiojiri municipality collected data to revitalize the community and improve safety from across multiple domains including disaster prevention, tourism, transportation, energy and environment. Data-utilization software was also used to share, analyse, process and visualize the data (see **Figure 13**).

[84] ITU-D SG2 Document 2/208 from NEC Corporation (Japan)

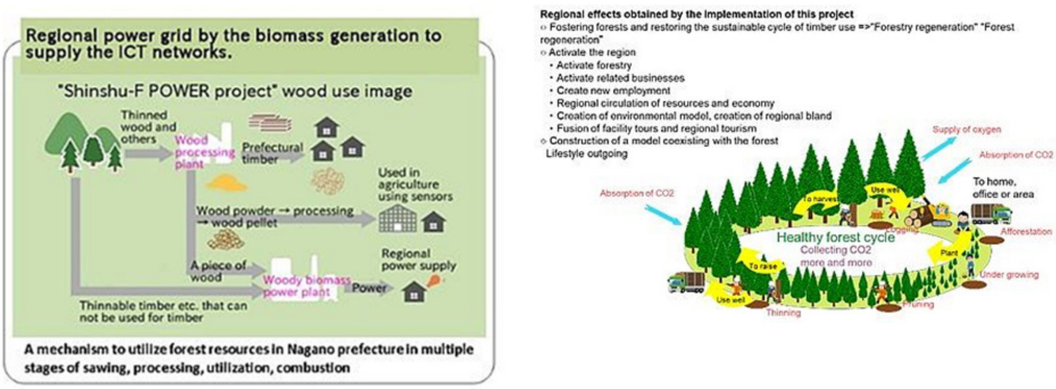
Figure 13: Case study of data-utilization software



Source: NEC Corporation, Japan

f) Shiojiri municipality has promoted the building of a biomass power plant that contributes to the sustainability of the regional forestry industry. The regional power grid enables sustainable power generation and supply to meet the regional demand for the ICT network and individual households. ICTs will be used to adapt the power grid to future power sector liberalization that will improve efficient electricity distribution in the region and maintain price stability in a competitive market (see **Figure 14**).[85]

Figure 14: Regional power grid using biomass generation to supply ICT networks and recycling of environmental materials



Source: Japan

g) Shiojiri City forests are being damaged by pine blight (pine wood nematode, see **Figure 15**) that could impact on the sustainability of the forest industry in this area. To

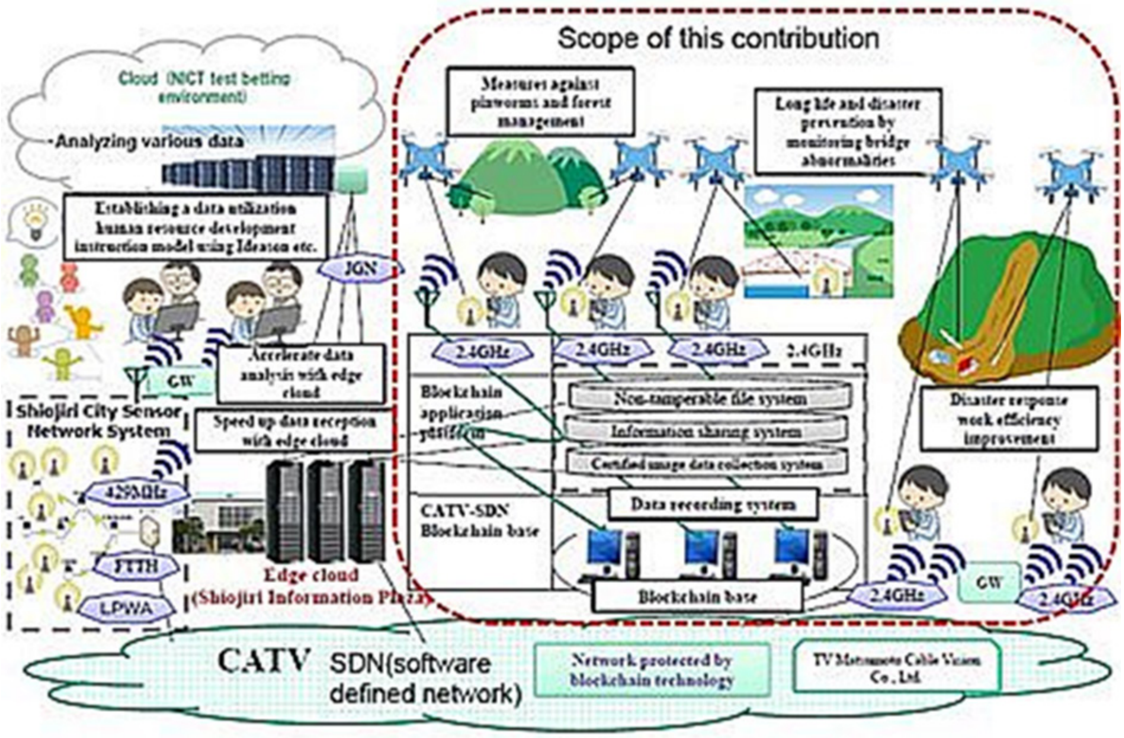
[85] ITU-D SG2 Document SG2RGQ/28+Annex from Japan

prevent further damage, ICTs were used to measure the condition of forests and create countermeasures to prevent the spread to other regions (see **Figure 16**).[86]

Figure 15: Forest with dead pine trees

Source: Shinshu University, Japan

Figure 16: Drone camera system



Source: Shinshu University, Japan

86 ITU-D SG2 Document SG2RGQ/173 from Shinshu University (Japan)

Chapter 5 – Climate-change countermeasures

5.1 Best-practice guidelines on climate-change monitoring and impact reduction

Although some frontier technologies are tackling climate change with the use of data-driven decision-making tools, some challenges remain, for example:

- the lack of data interoperability;
- the need for improved access to infrastructure, software and skills;
- the need for more networks to access, interpret and share big data;
- the need for better data resolution;
- limited discoverability of datasets;
- lack of financial support to maintain or renovate climate observation systems and to improve climate observation networks;
- need for greater diversity of systems and other non-technical issues.

However, there are also great opportunities because of data-driven applications, for example:

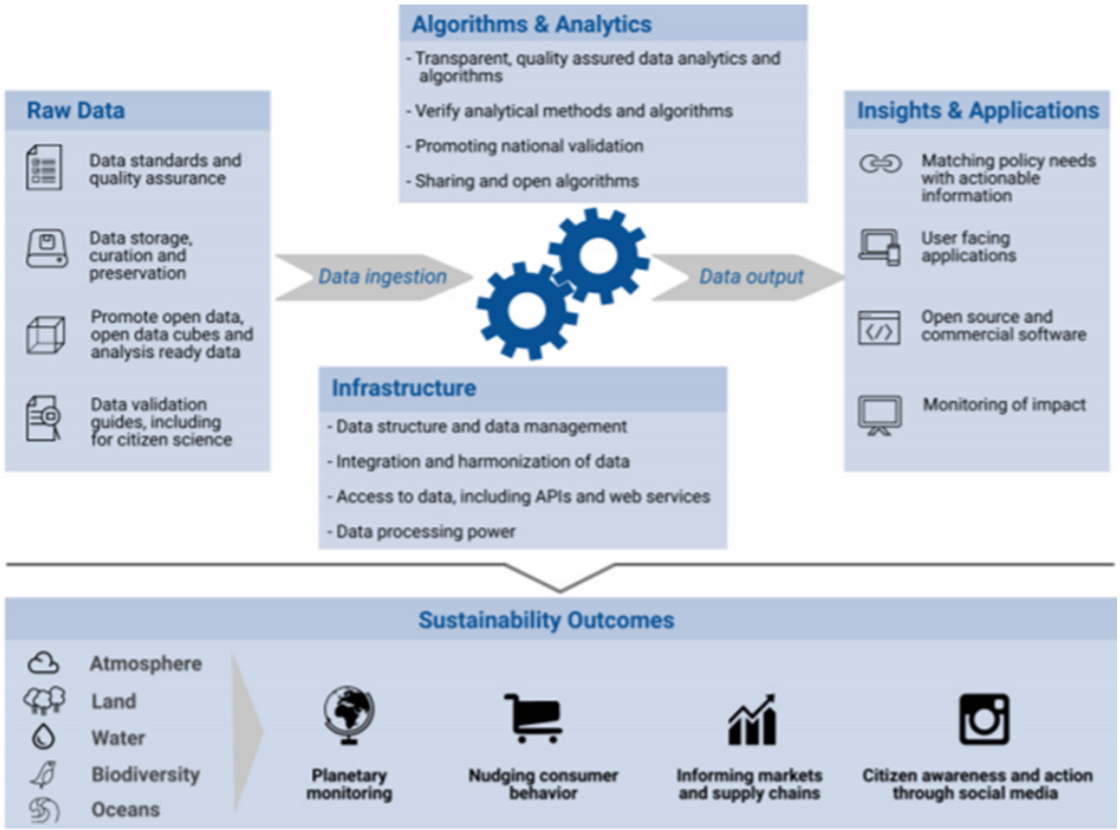
- improved decision-making tools;
- increased access to hazard related information and population data for a better understanding of the nature and drivers of risk;
- availability of predictive analytics to reduce risk, address impacts and strengthen resilience;
- better data resolution and early warning systems;
- more user-friendly tools for data exploration and analysis to understand the impact of climate change and the potential impact of long-term strategies;
- more data transformed into usable information for decision-makers and users;
- greater data- and information-gap filling.[87]

Focusing on technology and collaboration between public and private sector actors will lead to a digital ecosystem for the environment and climate that includes the co-creation of new governance models to leverage ICTs to monitor and achieve the SDGs, and will close the gap between data, decision-making and accountability. **Figure 17** illustrates the relationships in this digital ecosystem.[88]

[87] Maria Espinosa. Internal Displacement Monitoring Centre (IDMC). Internal displacement – the role of big data in monitoring climate and reducing the impacts of climate change. *ITU-D Workshop on Frontier ICTs for Climate Action*, Geneva, 15 October 2019.

[88] David Jensen. Crisis Management Branch, UNEP. Op. cit.

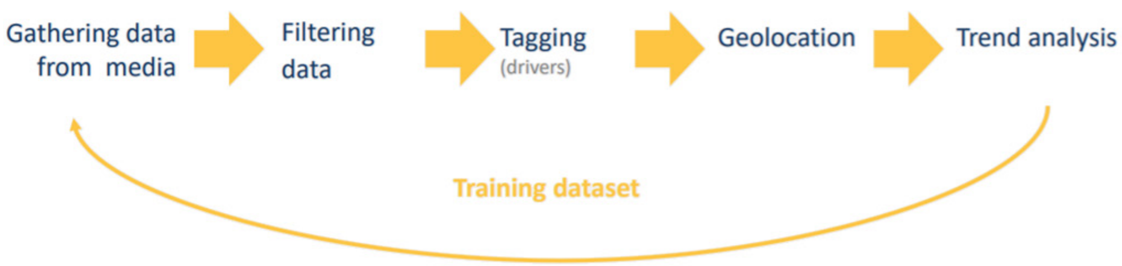
Figure 17: A digital ecosystem



Source: David Jensen (UNEP, 2019)[89]

Figure 18 shows how this can be used to establish a framework that uses datasets to train algorithms or machine learning models to predict trends or outcomes.

Figure 18: Framework for a training dataset



Source: Espinosa (IDMC), ITU Workshop on Frontier ICTs for Climate Action, 2019

ITU is essential for worldwide ICT development, standardization for spectrum allocation, technical regulations, satellite and terrestrial radio systems registration, international radio monitoring and interference reporting.

Further best practice guidelines will facilitate the use of technologies, especially in developing countries, for example Earth observation for climate change, the introduction of low-cost technology such as drones, small satellites, and the availability of data.

[89] Jillian Campbell and David Jensen (UNEP). Op. cit.

5.2 Technology for climate-change monitoring and impact reduction

The ICT sector, using new and frontier technologies, will promote solutions and innovation, from the management of cities to climate action for SDG 13.

Artificial intelligence and big-data tools capture, store, and analyse large and complex datasets, which require high-quality data (relevant and instantly available), and can be used to design, monitor and evaluate effective policies. Transforming the tsunami of big data into user-friendly insights that can support both decision-making and accountability for climate action in the digital ecosystem will need:

- establishment of global standards;
- disclosure of emissions data;
- data sharing and licensing;
- improved interoperability;
- better quality data and algorithms;
- reduction of the high fragmentation or limited strategic collaboration;
- increased numbers of stakeholders.[90]

As the world moves beyond COVID-19, governments can encourage greater use of ICTs to achieve environmental and climate-change goals and generate policy. In addition, new business models can include incentives for public-private partnerships, governance, privacy and data security, geopolitics and new ethical frameworks.

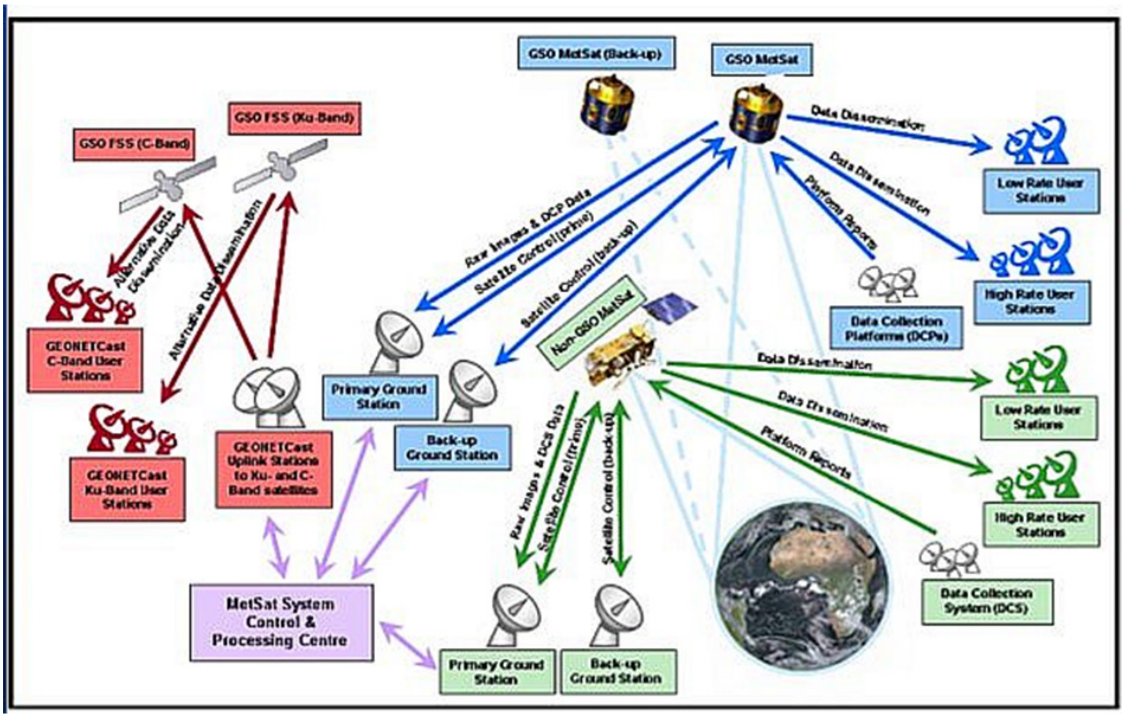
A public webinar[91] was recently organized by ITU-D to further understand how ICTs can be leveraged to fight climate change and rebuild greener economies after COVID-19.

5.3 Role of Earth observation on climate-change monitoring and impact reduction

Earth observation uses radio-frequency technology, for example, using satellite systems to illuminate objects or surfaces to be studied and capture the reflected signal for analysing various characteristics or phenomena. The general architecture of a meteorological satellite system is shown **Figure 19**.[92]

[90] David Jensen. Crisis Management Branch, UNEP. Op. cit.
[91] ITU. ITU-D Public Webinar on ICTs for climate action and rebuilding greener economies after COVID-19, 15 July 2020.
[92] Vadim Nozdrin (ITU Radiocommunication Bureau). Role of Earth observation in climate action. *ITU-D Workshop on Frontier ICTs for Climate Action*, 15 October 2019.

Figure 19: A meteorological satellite system



Source: ITU

A satellite system has high spatial resolution and unique sensitivity to a number of fluctuating land, sea and atmosphere parameters. According to the Coordination Group for Meteorological Satellites,[93] there are about 170 geostationary and non-geostationary meteorological satellites.

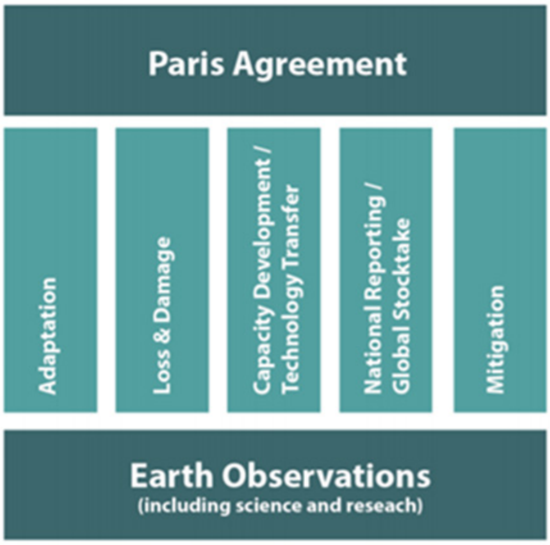
Earth observation is useful to monitor climate change because satellite data:

- provides benchmark measurements on key variables that contribute to the accuracy of climate models and projections, which inform policy decisions;
- contributes to obtain data on greenhouse gas (GHG) concentrations and emissions for carbon accounting in relation to mitigation responses;
- enhances of the development and monitoring of adaptation responses, including impact, vulnerability and risk assessment, when combined with other socioeconomic information over extended time scales;
- contributes to achieve 16 out of 17 SGDs, 40 out of 169 targets and 30 out of 232 SDG indicators;
- supports the Paris Agreement on climate change as shown in **Figure 20**.[94]

[93] Vadim Nozdrin, Op. cit.; and WMO (on behalf of CGMS). Space-based WMO Integrated Global Observing System, updated September 2020.

[94] Sara Venturini. Group on Earth Observations (GEO). EO in support of the Paris Agreement. *ITU-D Workshop on Frontier ICTs for Climate Action*, Geneva, 15 October 2019.

Figure 20: Earth observation and the Paris Agreement



Earth Observation (EO) applications are evolving to encompass:

- atmospheric pollution levels;
- forest observation to measure size and monitor biomass evolution and associated emissions;
- early-warning information;
- polar-ice extension and depth measurements;
- weather forecasting, climate monitoring and operational oceanography;
- precipitation radar to understand the interactions between water vapour, clouds and precipitation.

ITU is engaged in ongoing work in all its three Bureaux, providing guidelines on the provision of satellite remote sensing data for the purpose of studying climate change; a summary of the status of major climate variables and forcing factors; and protection of science-service spectrum. It has also published a handbook in collaboration with WMO on the use of radio spectrum for meteorology.[95]

[95] ITU and WMO. Handbook on Use of Radio Spectrum for Meteorology: Weather, Water and Climate Monitoring and Prediction. 2017.

Chapter 6 – Conclusions

6.1 Future of e-waste

E-waste, the fastest growing waste sector, has an impact on the environment and on health. The challenge is to create e-waste management infrastructures and systems, and to generate greater awareness of the impact of illegal trading, informal recycling, loss of valuable resources and environmental consequences of e-waste.

E-waste management and policy should focus on supporting a circular-economy vision that emphasizes the importance of recycling and refurbishment. In many cases, the dangers of e-waste collection are most pronounced when waste ends up in the hands of unregulated and informal sectors.

Design must include the product end-of-life cycle, and the provision of financial support and tax incentives should be part of policy, along with emphasis on skills development of the informal sector, scientific disposal and better reuse and refurbishing of products.

Natural resources are limited and reclaiming them through scientific management of e-waste is a viable solution to resource shortages. Stakeholder flexibility is essential, for example in product design and innovative methods of e-waste disposal, but it is important to ensure:

- regulations for e-waste manufacturing processes to reduce and eliminate toxic substances;
- technology development for end-of-life products by material substitution and recovery;
- knowledge sharing and synergies among the main actors;
- integrated support, as well as practical and stringent national policies, especially in emerging economies;
- further coordination between UN agencies;
- capacity building and innovation, focusing on productive employment generation;
- reclaiming of valuable natural resources, while ensuring health, industry sustainability, and economic growth;
- better e-waste collection and reuse;
- more efficient and effective EPR-based e-waste management;
- all stakeholders support sustainable consumption practices.

6.2 Climate change, the way ahead

This report shows how important telecommunications/ICTs are to the provision of services and applications, especially those dedicated to the reduction of global warming. The WMO report United in Science 2020[96] showed that greenhouse gas concentrations are at unprecedented levels, and emissions are again reaching pre-pandemic levels. The world is set to witness the warmest five years on record,[97] and there have been thousands of wildfires in 2020, covering a record 2.2 million acres, displacing people and perpetuating global temperature increases that

[96] WMO. Resources. United in Science 2020. A multi-organization high-level compilation of the latest climate science information.
[97] World Wide Fund for Nature (WWF). Stories. 2020: A critical year for our future and for the climate.

will make it harder to meet agreed targets to stay below 2°C or at 1.5°C above pre-industrial levels.

In order to succeed in climate-change mitigation, socially and culturally appropriate policy needs to ensure cost-effective, readily available and sustainable technology. Mitigation measures that focus on emerging solutions are costly, and the ongoing process of climate-change adaptation is complex. Approaches involving adaptable policy and technology should be utilized simultaneously to find sustainable solutions.

Progress in ICTs and frontier technologies offers the scope to reduce the adverse impact of climate change and has the potential to support preventive action. The development of powerful tools such as AI, Earth observation, and big data can bring options and opportunities to enable scientific support for resilient and sustainable climate action.

Member States need to implement multilateral environmental agreements that will bring together nations, the environmental community and research bodies to face and overcome the biggest challenges of e-waste and climate change and ensure a better and sustainable quality of life.

Annexes

Annex 1: Bibliography and online resources

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Annex 2: List of contributions and liaison statements received on Question 6/2

Contributions on Question 6/2

Web	Received	Source	Title
2/394	2021-02-19	Russian Federation	Environmental responsibility of communication operators, the Russian Federation's national experience
2/382	2021-01-26	BDT Focal Point for Question 6/2	ITU-D activities on ICTs and the environment
RGQ2/276	2020-09-22	BDT Focal Point for Question 6/2	ITU-D activities on ICTs and the environment
RGQ2/247	2020-09-06	ITU Association of Japan (Japan)	Update of recycling method of lead acid battery since 2016
2/335	2020-02-11	Shinshu University (Japan)	Proposed draft text for Chapter 1, Part 3 on climate change for the Final Report of Question 6/2
2/293	2020-01-09	Senegal	Proposed text for Chapter 2 of the Final Report on Question 6/2: "How to develop an e-waste management strategy"
2/291	2020-01-08	BDT	Outcome from the Policy Awareness Workshop on E-waste held in Hyderabad, India
2/285	2020-01-07	BDT Focal Point for Question 6/2	ITU-D activities on ICTs and the environment
2/282	2020-01-04	India	Proposed text for Final Report for Question 6/2, e-waste background
2/281	2020-01-04	India	Resource efficiency towards circular economy strategy
2/274	2020-01-02	Benin	Texte proposée pour le Chapitre 1 du Rapport Final lié aux déchets électroniques/sensibilisation à l'éducation
2/270	2019-12-31	Burundi	Management of Waste Electrical and Electronic Equipment (WEEE) in Burundi: "National and regional initiatives"
2/249	2019-12-05	Cameroon	Proposed text for Chapter 2 of the Final Report on the development of a strategy for managing electrical and electronic waste
RGQ2/197	2019-09-24	India	Proposed text for the Final Report of Q6/2
RGQ2/173	2019-09-19	Shinshu University (Japan)	Development of technology to solve pine blight countermeasure problems using drones
RGQ2/141	2019-08-12	BDT Focal Point for Question 6/2	ITU-D activities on ICTs and the environment
RGQ2/132	2019-07-26	India	Emerging Economies and ICT solutions - role in climate change mitigation

(continued)

Web	Received	Source	Title
RGQ2/119	2019-07-02	Cameroon	ICTs and the environment: management of waste electrical and electronic equipment (WEEE) in Cameroon
RGQ2/109	2019-03-14	Sri Lanka	E-waste management initiatives in Sri Lanka
2/214	2019-03-12	Brazil	Regional needs for e-waste management for developing countries
2/213	2019-03-12	BDT Focal Point for Question 6/2	ITU-D activities on the ICTs and the environment
2/211	2019-03-12	Intel Corporation (United States)	Importance of smart cities, 5G, IoT and AI
2/197	2019-03-05	India	E-waste management in India - circular economy vision
2/145	2019-01-18	Cameroon	Challenges of climate change in the North Cameroon region
2/143	2019-01-16	Burundi	Ecological management of waste electrical and electronic equipment (WEEE) in Burundi
RGQ2/87	2018-09-27	BDT	Extracted lessons learned from contributions to ITU-D Study Group 2 Questions (ITU-D Study Group 2 Rapporteur Group Meetings)
RGQ2/84 +Ann.1	2018-09-18	BDT Focal Point for Question 6/2	ITU-D activities on the ICTs and the environment
RGQ2/81	2018-09-18	ITU General Secretariat	WSIS Stocktaking and WSIS Prizes 2019: calls for action
RGQ2/76 +Ann.1	2018-09-18	Japan	Tokyo 2020 Medal Project: towards an innovative future for all
RGQ2/72	2018-09-18	India	Role of ICT in cleanliness mission in India thus helping in minimizing harmful effects of e-waste, solid wastes and ground pollutants
RGQ2/52	2018-09-04	Russian Federation	Review of the current legislation of the Russian Federation in the field of WEEE management
RGQ2/51	2018-09-03	African Civil Society for the Information Society (ACSIS)	ACSIS contribution on ICT and the environment
RGQ2/37	2018-08-16	Brazil	Brazilian Federal Law on Solid Waste and WEEE
RGQ2/36	2018-08-16	Brazil	The Brazilian System of Reverse Logistics for WEEE
RGQ2/29 +Ann.1	2018-08-15	Daiwa Computer Co. (Japan)	ICT-applied farming method for producing muskmelon by an IT company
RGQ2/28 +Ann.1	2018-08-15	Japan	Proposal for the sustainable smart society
2/TD/5	2018-05-07	Rapporteur for Question 6/2	Draft work plan for Question 6/2

(continued)

Web	Received	Source	Title
2/87	2018-04-23	BDT Focal Point for Question 6/2	ITU-D activities on the ICTs and the environment
2/65	2018-04-06	Brazil	Topics for the study of Question 6/2 for the next study period
2/48	2018-03-15	Burundi	Establishing regulations on the management of waste electrical and electronic equipment in Burundi

Incoming liaison statements for Question 6/2

Web	Received	Source	Title
2/365	2021-01-12	ITU-T Study Group 2	Liaison statement from ITU-T Study Group 2 to ITU-D SG1, ITU-SG2 Question 5/2 and Question 6/2 on establishment of a new ITU-T Focus Group on Artificial Intelligence for Natural Disaster Management (FG-AI4NDM) and first meeting (Virtual, 15-17 March 2021)
RG2/203	2020-02-18	ITU-T Study Group 5	Liaison statement from ITU-T SG5 to ITU-D SG1 and SG2 on information on WTSA-20 preparation
2/258	2019-12-20	ITU-T FG-AI4EE	Liaison statement from ITU-T FG-AI4EE to ITU-D Study Group 1 and 2 on the first meeting of ITU-T Focus Group on Environmental Efficiency for Artificial Intelligence and Other Emerging Technologies
RGQ2/TD/5	2018-09-28	ITU-T Study Group 5	Liaison statement from ITU-T SG5 to ITU-D SG2 Q6/2 on Question 6/2 work for the 2018-2020 study period (reply to ITU-D SG2, 2/115-E)
2/33	2017-11-28	ITU-T Study Group 5	Liaison Statement from ITU-T SG5 to ITU-D study groups on setting environmental requirements for 5G/IMT-2020
2/28	2017-11-24	ITU-T Study Group 5	Liaison Statement from ITU-T SG5 to ITU-D SG2 Q6/2 on previous Q8/2 draft report for the 2014-2017 study period
2/26	2017-11-24	ITU-T Study Group 5	Liaison Statement from ITU-T SG5 to ITU-D SG2 Question 6/2 and Question 7/2 on Operational Plan for Implementation of WTSA Resolutions 72 and 73 (Rev. Hammamet, 2016), and Resolution 79 (Dubai, 2012)
2/17	2017-11-22	ITU-T Study Group 3	Liaison Statement from ITU-T SG3 to ITU-D SG2 Q6/2 on previous Q8/2 work for the 2014-2017 study period

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