2050 ELECTRICAL & ELECTRONIC WASTE OUTLOOK IN WEST ASIA

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FOREWORD

Foreword

Electronic and electrical waste (e-waste) can contain hazardous components that can be harmful to the environment and human health and hinder the achievement of the Sustainable Development Goals (SDGs). Their Generation has increased drastically over the last decade in the world, including in West Asia region, where several countries face the challenge of managing their e-waste.

The 2050 Electronic and Electrical Waste Outlook in West Asia publication is a collaborative effort of the United Nations Environment Programme Regional Office for West Asia and the UN Institute for Training and Research (UNITAR). The Outlook provides projections for e-waste generation and challenges of managing e-waste in an economically diverse West Asia region. It estimates that the e-waste generation is likely to more than double over the next 30 years in a 'Business as Usual' scenario, from 1.5 Mt in 2020 to 3.1 - 3.9 Mt in 2050.

The Outlook also provides a stepwise approach for countries to manage e-waste in an environmentally sound manner. E-waste is a source that can be utilised for economic growth, creating new jobs and investment opportunities. Both consumers and producers have a key role in the sustainable and environmentally sound management of e-waste. Few countries in the region are taking action and working toward mitigating e-waste; nonetheless, much more progress is needed. This publication also puts forth recommendations and opportunities for transitioning from a linear economy toward a circular economy to manage e-waste in an environmentally sound manner and utilise e-waste as a source for economic, social, and environmental benefits.

A transition toward a circular economy approach will have positive impacts on both the reduction of the amount of electronic and electrical equipment placed on the market, as well as on the e-waste generation. Enhancing collection systems, increasing reuse and recycling facilities for e-waste, producing electrical and electronic equipment that have longer lifespans, and efforts to raise awareness to consumers in the West Asia region are all vital in addressing the e-waste challenge.

We strongly believe that this publication will inspire policymakers, the private sector, and other stakeholders in West Asia and beyond to take appropriate measures to manage their e-waste in an environmentally sound manner, thereby protecting the people and the environment from adverse impacts of e-waste.
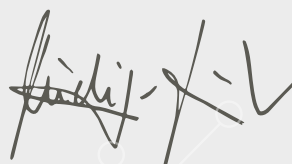
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Contents

Glossary

BaU	Business as Usual
CE	Circular Economy
EEE	Electrical and Electronic Equipment
EEE POM	Electrical and Electronic Equipment Placed On the Market
EPR	Extended Producer Responsibility
E-waste managed environmentally soundly	
	E-waste that is depolluted, with hazardous parts disposed of in an environmentally sound manner and with recyclable components properly recycled
E-waste	Waste electrical and electronic equipment with circuitry or electrical components and a power or battery supply. E-waste includes any product supplied to the national market for consumption and use by households, businesses, and public authorities
E-waste generated	Generated e-waste resulting from EEE that had been POM in that country, prior to any other activity, such as collection, preparation for reuse, treatment, or recovery
E-waste recycling rate	Calculated by dividing 'E-waste managed environmentally soundly' by 'E-waste generated'
IT	Information Technology
GDP	Gross Domestic Product
POM	Placed On the Market
PPP	Purchasing Power Parity
Mt	Megaton (1,000,000 t, or 1,000,000,000 kg)
UNU-KEY	Product-based classification distinguishing 54 products, used to measure e-waste statistics
Unmanaged e-waste	E-waste that is not treated by environmentally sound facilities. Calculated by subtracting 'E-waste managed environmentally soundly' from 'E-waste generated'
SCYCLE	Sustainable Cycles Programme
SSP	Shared Socioeconomic Pathways
t	tonne, 1,000 kg
UNEP	United Nations Environment Programme
UNITAR	United Nations Institute for Training and Research
WEEE	Waste Electrical Electronic Equipment

Executive Summary

In the West Asia region – which includes Bahrain, Iraq, Jordan, Kuwait, Lebanon, Oman, State of Palestine, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, and Yemen – 99.9% of electrical and electronic waste equipment (e-waste) is currently unmanaged or mismanaged. The e-waste ends up in landfills or managed by the informal sector, causing severe health and environmental impacts, due to the release of hazardous substances, emissions of greenhouse gasses, and loss of critical material resources. In this report, the future of e-waste management in West Asia is assessed to 2050 for two contrasting scenarios. The Business as Usual (BaU) scenario represents present-day consumption, lifespans, and recycling behaviours, extrapolated to 2050 with adjustments from economic and demographic drivers. Alternatively, the Circular Economy (CE) scenario assumes that products become more durable, are shared and reused more, and are managed in an environmentally sound manner when becoming e-waste, while the population still has access to the same functionality that EEE can offer under the BaU scenario.

In the BaU scenario, both the amount of electrical and electronic equipment (EEE) placed on market (POM) in the region and e-waste generation will more than double by 2050. In this scenario, EEE POM increases from 2.2 Mt (million metric tonnes) in 2020 to 4.8 - 7.5 Mt in the year 2050. The range here represents expected long-term variations in economy and population in West Asia, as well as the underlying differences in decarbonisation rates and the associated solar photovoltaic panel installations. The amount of e-waste generated is projected to steadily increase from 1.5 Mt in 2020 to 3.3 - 3.9 Mt in 2050.

The CE scenario could have a 33% decrease on EEE POM as compared to the BaU scenario, even though it would still lead to a growth from 2.2 Mt in 2020 to 3.1 - 5.6 Mt in 2050. The CE scenario could also have a 14% decrease in e-waste generated as compared to BaU, but still with an overall increase of e-waste generated from 1.5 Mt in 2020 to 2.9 – 3.4 Mt in 2050. The e-waste generated shows a delayed response to the CE transition due to longer lifespans of products. It is expected that the CE effects are going to be a lot more pronounced in e-waste generated in the latter parts of the 21st century. The fastest growing e-waste, both in relative and absolute terms, is that of photovoltaic panels, which are limited in the e-waste stream in 2020 and which are expected to experience immense growth rates, reaching 6% of the total weight of the e-waste stream.

Total EEE POM and e-waste generated are projected to grow faster in the low- and middle-income countries in West Asia than in the high-income countries. As a result, the middle- and lower-income sub-region in West Asia could overtake the higher-income sub-region in terms of the total quantity of POM and e-waste generated in the latter parts of the century.

The potential benefits of the transition toward the CE scenario are vast, both for resource recovery and emission reductions of hazardous substances. Cumulatively, between 39 and 43 Mt of e-waste is projected to be managed in West Asia from 2020 to 2050, assuming the e-waste collection rate gradually reaches 100% by 2050 as part of the

CE scenario. An estimated total of 130 t of gold, 5 t of rare earth metals, 17 Mt of iron and steel, 1.5 Mt of copper, and 2.6 Mt of aluminium could be recycled between 2020 and 2050. Simultaneously, a larger proportion of hazardous materials and greenhouse gases will be managed in an environmentally sound manner, leading to mitigated emissions of up to 6 t of mercury, 60 t of cadmium, and 53 Mt CO_2-eq of fugitive emissions of refrigerants between 2020 and 2050. It is estimated that roughly 225,000 FTE (full-time equivalent) jobs would be created by 2050 for repair of used EEE and collection and pre-treatment of e-waste.

In order to realise the benefits of the CE scenario, a considerable effort must be made in capital investments to set up e-waste management infrastructure, develop the right legislation, and raise consumer awareness of the issue across the entire West Asia region. Strong long-term binding targets, aiming to reach 100% e-waste collection rates by 2050 (or preferably earlier), are the only way to slow down and reverse the growth of the unmanaged e-waste. Specifically, the high-income countries could serve as one of the vehicles for devising and becoming early adopters of effective e-waste policies in the region.

Therefore, immediate and adequate e-waste management measures should be taken throughout the region, as summarised in the following 10 steps:

1. Establish a clear legal framework for e-waste collection and recycling.
2. Introduce extended producer responsibility to ensure that producers finance the collection and recycling of e-waste.
3. Enforce legislation for all stakeholders and strengthen monitoring, statistics, and compliance mechanisms across the country to ensure a level playing field for all, including socially disadvantaged groups and women.
4. Create favourable investment conditions for experienced recyclers (both female and male) to bring the required technical expertise to the country.
5. Create a licensing system or encourage certification via international standards for collection and recycling.
6. Develop a wide network of collection points or collectors to separately collect all e-waste generated at the source.
7. When no local end-processing facilities exist for an e-waste part, ensure good and easy access to international licensed treatment facilities.
8. Ensure that costs to run the system are transparent and that they stimulate competition in the collection and recycling system, driving cost effectiveness.
9. Ensure that all stakeholders involved in e-waste collection and recycling are aware of the potential gender-differentiated impacts on the environment and human health, as well as possible approaches to the environmentally sound treatment of e-waste.
10. Create targeted gender-differentiated awareness campaigns among consumers regarding circular economy and such an economy's environmental benefits.
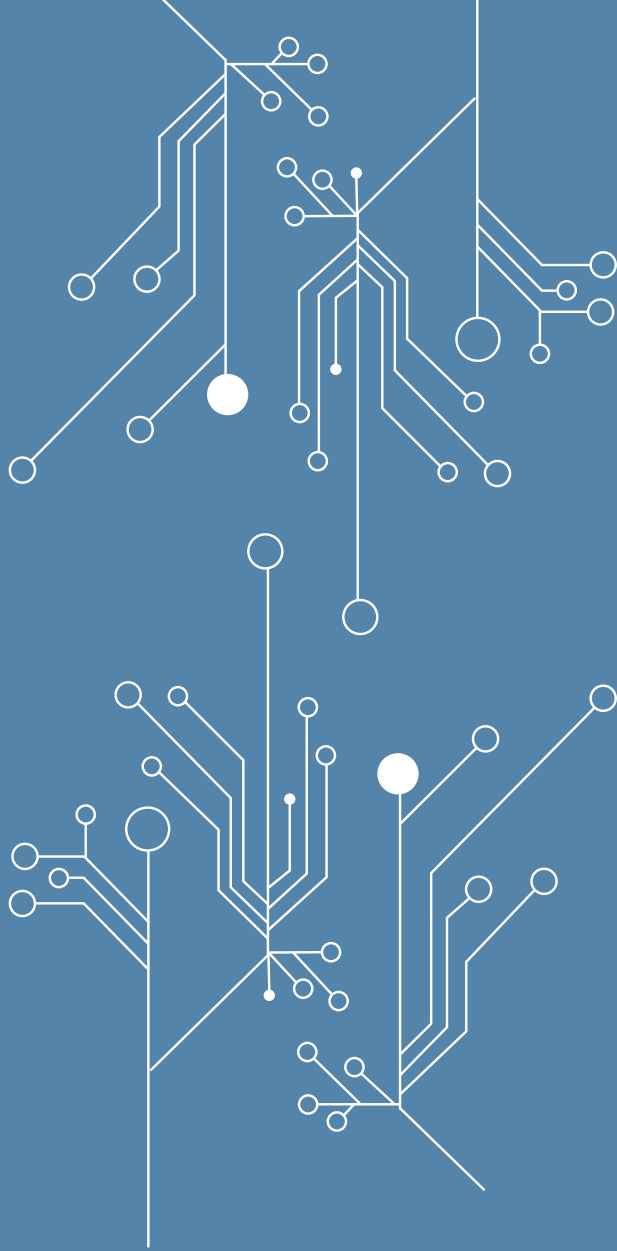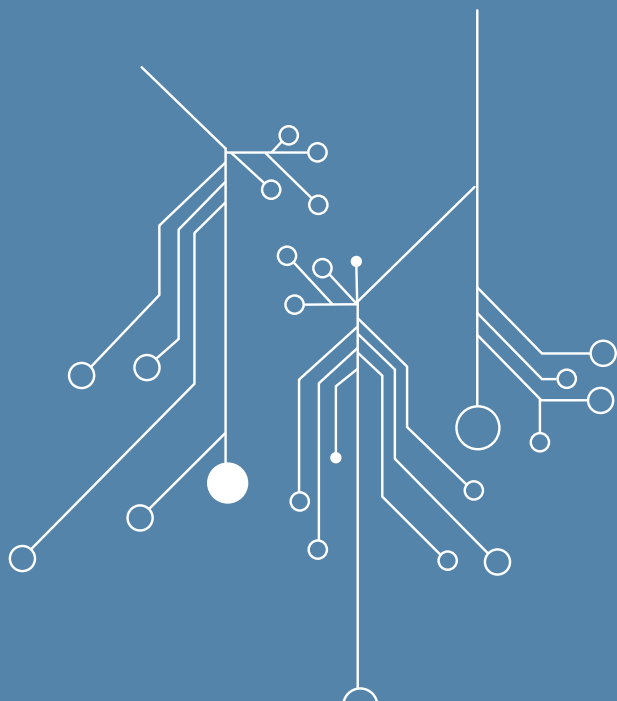
INTRODUCTION

1. Introduction

The term electrical and electronic equipment (EEE) refers to any household or business item (excluding vehicles) with circuitry or electrical components and a power or battery supply. The term EEE covers any product supplied to the national market for consumption and use by households, businesses, and public authorities. Once EEE is discarded by its owner, it becomes waste, and is referred to as waste electrical and electronic equipment (WEEE, or e-waste). The fast-growing quantities of e-waste comprise a major global issue. In 2019, 53.6 Mt (million metric tonnes) of e-waste were generated globally, equal to 7.3 kg/capita, and only 17% of it was managed environmentally soundly (Forti et al. 2020). The vast majority of EEE is mismanaged and creates considerable material losses of valuable commodities such as steel, aluminium, copper, and rare earth metals, leading to a greater pressure to extract new raw materials and causing more indirect environmental impacts as a result.

EEE also poses serious environmental hazards – directly, through the release of hazardous substances such as cadmium, lead, mercury, and brominated flame retardants, as well as indirectly, through greenhouse gases and ozone-depleting substances in refrigerants. In addition, a greater need for raw materials resulting from low e-waste recycling rates leads to larger indirect environmental impacts, including more greenhouse gas emissions. These problems are particularly acute in the countries with under-developed e-waste collections and recycling systems. In developing countries where there is a large informal sector and low labour-force costs, the collection and manual dismantling (followed, unfortunately, by hazardous recycling and value generation practices) is typically very common (UNEP & StEP Initiative 2009) (Forti et al. 2020). Integrated and complex metal and precious metal-containing components and parts, such as circuit boards and cell phones, can be best-recycled by high-tech state-of-the-art facilities. Likewise, batteries should be routed to specialised battery recycling plants that

INFOGRAPHIC 1: **Global Status of E-waste from the Global E-waste Monitor, Source Forti et al. 2020**

53.6 Mt
GLOBAL E-WASTE GENERATED IN 2019

E-WASTE IS A FAST-GROWING WASTE STREAM

CONTAINING BOTH VALUABLE MATERIALS

Plastic
Gold
Steel
Rare Earth Metals
Aluminium
Copper

$57 Billion USD
Value of raw materials in e-waste

AND TOXIC SUBSTANCES

Greenhouse gas emissions
Brominated Flame Retardants (BFR)
Lead
Mercury

17%
Documented to be collected and recycled in an environmentally sound manner by depolluting it and recycling the valuable materials

83%
Undocumented most likely landfilled or treated with inferior standards

have the capabilities to recover the material and value content with maximum efficiency. Few such facilities exist globally and are located mainly in industrialised countries.

The West Asia region – which includes Bahrain, Iraq, Jordan, Kuwait, Lebanon, Oman, State of Palestine, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, and Yemen – is characterised by inadequate e-waste management systems across the board (Table 1), regardless of the income level of an individual country. Only 0.1% of e-waste is currently managed in an environmentally sound manner. The vast majority of e-waste ends up in landfills or is managed by the informal sector, causing considerable material losses and environmental and health impacts (Iattoni et al. 2021).

TABLE 1: Estimated amounts of e-waste generated and collected in West Asia in 2019, and the resulting collection rate (Iattoni et al. 2021).

	E-WASTE GENERATED		E-WASTE COLLECTED AND MANAGED ENVIRONMENTALLY SOUNDLY		COLLECTION RATE
	kt	kg/inh	kg/inh	kt	(%)
Saudi Arabia	595	17.6			n/a
Bahrain	24	15.9			n/a
Kuwait	74	15.8			n/a
Oman	69	15.8			n/a
United Arab Emirates	162	15.0	0.06	0.6	0.4%
Qatar	37	13.6	0.07	0.2	0.5%
Lebanon	50	8.2			n/a
Iraq	278	7.1			n/a
Jordan	53	5.3	0.13	1.3	2.4%
Syrian Arab Republic	91	5.2			n/a
State of Palestine	20	4.0	0.02	0.1	0.4%
Yemen	48	1.5			n/a
Total / average	**1,500**	**9.0**	**0.3**	**2.2**	**0.1%**

To help improve e-waste management in West Asian countries, we utilised the existing regional statistics on electrical and electronic equipment placed on the market (EEE POM), lifespans, e-waste generated, and e-waste collection and recycling in order to create long-term projections for West Asia.

Two contrasting scenarios have been developed:

1) The Business as Usual (BaU) scenario, which represents present-day consumption, lifespan, and recycling behaviours extrapolated to 2050 with adjustments from economic and demographic drivers

2) The Circular Economy (CE) scenario, in which product lifespans are projected to increase due to more reuse, repair, and remanufacturing, while sharing of certain equipment becomes more common, and e-waste collection and recycling infrastructure is incrementally developed until 100% collection rates are reached in 2050

A long-term horizon such as 2050 is required to capture relatively slow processes associated with changes in consumer behaviour and technology, the underlying regional and global socioeconomic trends, and the lags between new products being sold and their becoming e-waste (Baldé et al. 2015; Forti et al. 2020). The mid-century assessment horizon is also in line with the existing comparable policy pledges, e.g. the net zero carbon emissions target by 2050 established by several high-income countries such as the United Kingdom, United States of America, and countries in the European Union. Having a committed long-term policy roadmap spanning several decades is essential for addressing large-scale and systemic challenges such as e-waste and climate change.

This report begins with a brief description of the methodology employed herein, followed by the key results for the 2050 electrical and electronic equipment placed on the market (EEE POM) and e-waste generation in West Asia. Results are provided for the West Asia region as a whole and then are further broken down for high-income and middle- and low-income country groups, as well as into seven broad EEE product types. A separate section is dedicated to projected impacts of the CE transition pathway on e-waste outcomes in West Asia by 2050, focusing on the associated opportunities to avert environmental and health impacts and recycle valuable materials. The report concludes with an overview of policy recommendations and a country-level stepwise approach to e-waste management. Further methodological details and supplementary results are provided in the ANNEX.
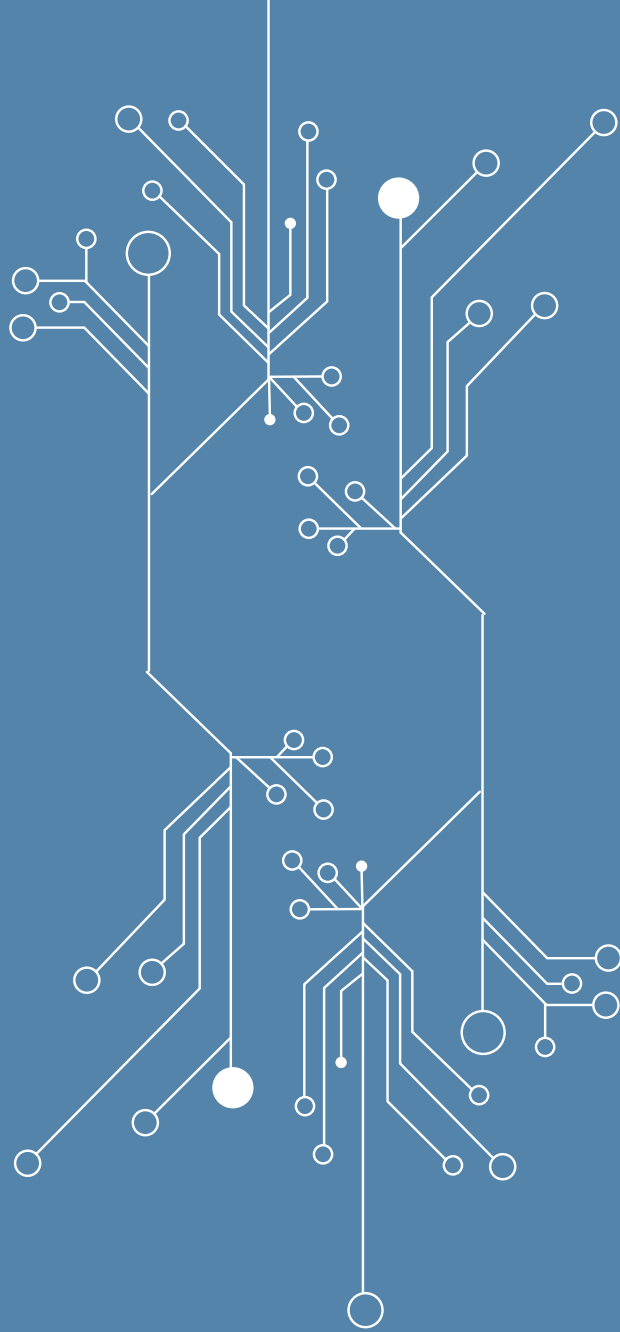
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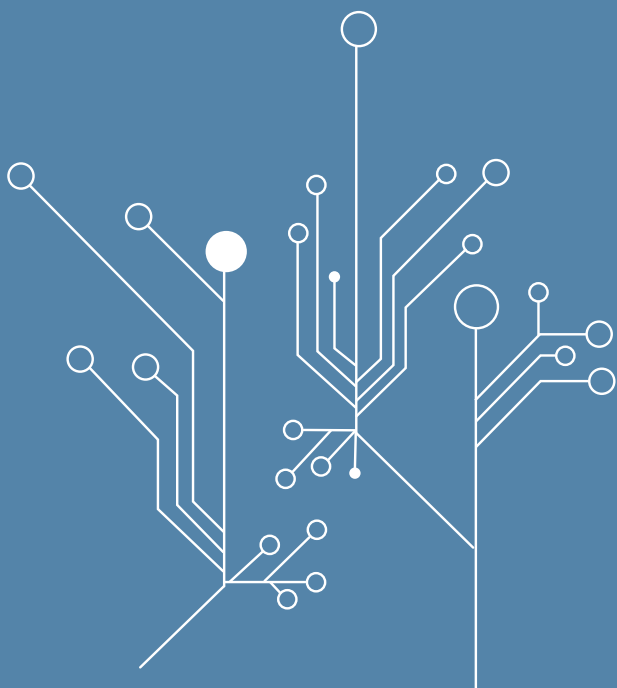
2. Methodology

2.1 E-waste Statistics Framework

The measurement framework of e-waste projections follows a mass balance approach over the entire life cycle of EEE. This approach is consistent with the global e-waste statistics guidelines (Baldé et al. 2015; Forti et al. 2018). The approach covers production, imports, placing on the market, e-waste generation, e-waste management, and other e-waste-related activities (Figure 1). It covers any product supplied to the national market for consumption and use by households, businesses, and public authorities. Calculations were made for 54 products – the so-called UNU-KEYs. The UNU-KEYs are a product-based classification in which each UNU-KEY has a homogeneous lifespan, average weight, material composition, and hazardousness profile. The UNU-KEYs can be linked to the six e-waste categories and are used to measure e-waste statistics (see ANNEX 7.1).

The six e-waste categories used in this report are as follows
(with the fourth category being split into two sub-categories):

I   Temperature Exchange Equipment

II   Screens and Monitors

III   Lamps

IV-a   Large Equipment (excluding photovoltaics)

IV-b   Photovoltaics

V   Small Equipment

VI   Small IT and Telecommunication Equipment

The first step of the measurement framework is to quantify the amount of EEE placed on market (EEE POM); see Figure 1. After a product has been placed on the market, it remains in use – or at the household, business, or governmental institute – until it is discarded.
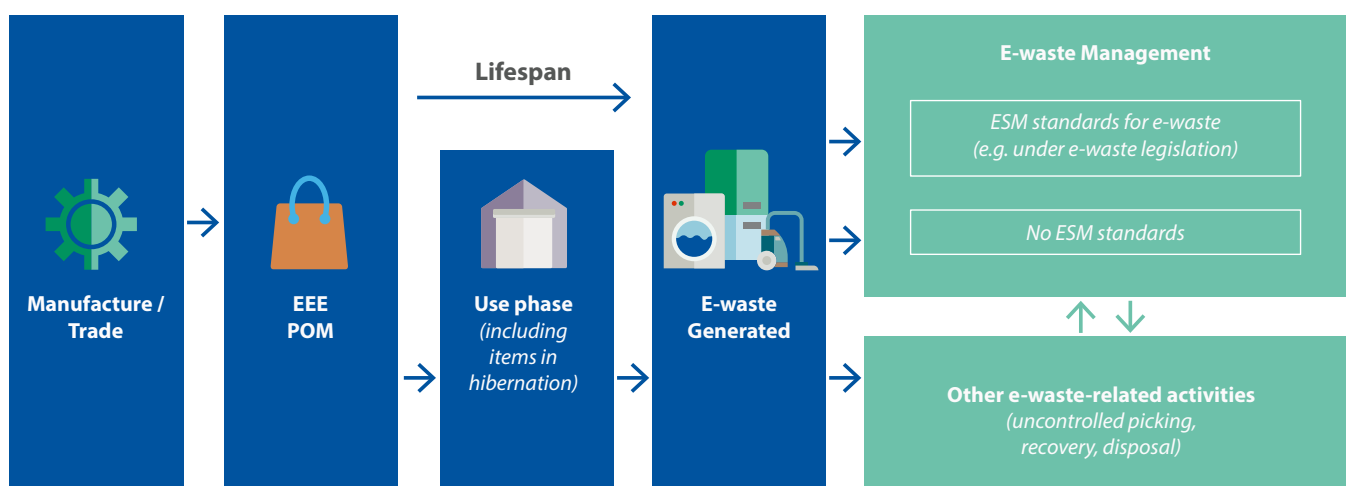
FIGURE 1: **E-waste Statistics Framework**

A product's lifespan is the period of time from when it is placed on the market until it becomes e-waste (see Figure 2). This includes the hibernation phase – such as the storing/stockpiling of the equipment until POM or the hoarding time of the equipment prior to actually being discarded at the end of its life – as well as the passing on of the equipment from one owner to another (reuse). The lifespan of EEE is expressed as a Weibull function and varies per UNU-KEY, with the shape and scale parameters associated with the average lifespan for each UNU-KEY individually. After a certain lifetime sampled from the Weibull function, the product is disposed of and becomes waste. E-waste generated in a country refers to the total weight of e-waste resulting from EEE that had been POM in that country, prior to any other activity, such as collection, preparation for reuse, treatment, or recovery, including recycling and export.
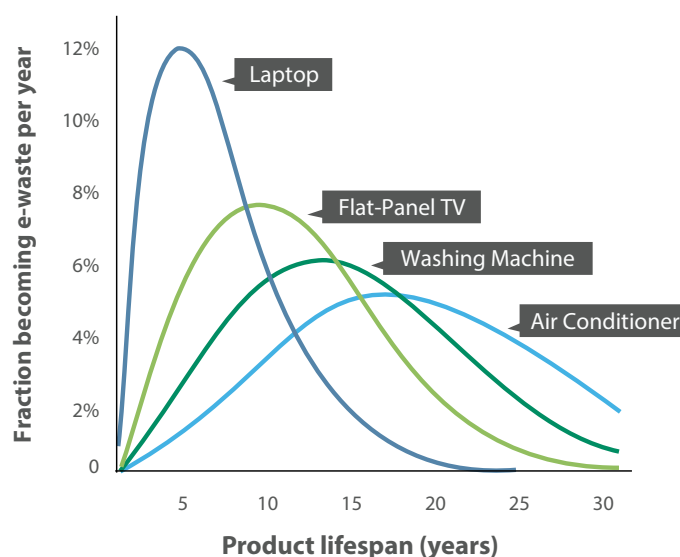
FIGURE 2: Examples of EEE product lifespans

In general, e-waste management involves the collection, transportation, storage, and disposal of waste, including after-care of disposal sites. It can be undertaken by an economic unit within a legal framework, but waste handling carried out by informal economic units (e.g. informal waste-picking) and illegal waste handling also exist. In this context, 'waste management' is differentiated from 'other waste-related activities', as proposed by the UNECE's Waste Statistics Framework ((United Nations Economic Commission for Europe [UNECE] 2021). The 'other waste-related activities' include waste dumping, waste-picking, disposal, etc. and may include the informal sector.

It is vitally important that e-waste undergoes decontamination, that hazardous fractions are disposed of in an environmentally sound manner, and that recyclable components are properly recycled. This is typically, but not exclusively, performed under the requirements of national e-waste legislation. Therefore, in this report and in the e-waste statistics guidelines, the e-waste flow is referred to as 'e-waste formally collected'. This term implies that the e-waste is collected under the specific legislation for e-waste (or in a similar manner) and is also referred to as 'e-waste managed environmentally soundly'.

2.2 E-waste Projections to 2050

The flows of generated e-waste are projected using the same framework as the e-waste statistics described in section 2.1 and are split into two scenarios: a Business as Usual scenario (BaU) and a Circular Economy scenario (CE).

EEE POM from 1980 to 2020 was obtained from the readily available country-level data, collected as part of the regional e-waste monitor for West Asia (Iattoni et al. 2021). The historic solar photovoltaic installation figures for the West Asian countries, which form the fastest-growing part of POM, were downloaded from a global dataset compiled by the Internati onal Renewable Energy Agency (IRENA). The POM data has been broken down into relatively detailed product groups (UNU-KEYs; 54 groups in total). It is projected into the future with an empirical relationship between EEE POM and country-level scenarios for purchasing power parity (PPP) Gross Domestic Product (GDP) per capita, established from the global historic EEE POM and GDP data (Forti et al. 2020). We use GDP PPP and population scenario projections from the Shared Socioeconomic Pathways (SSPs), which represent a plausible range of regional and global socioeconomic futures with various degrees of cooperation, competition, urbanisation, education, technological development, and other relevant indicators (Riahi et al. 2017). The SSP scenarios are described in detail in the subsequent section.

In the BaU scenario, present-day consumption patterns for EEE goods are projected to 2050 with some adjustments according to the underlying economic conditions, population, consumer behaviour, product lifespans, and e-waste management infrastructure (see Table 2).

In the CE scenario, additional behavioural and/or technological changes are assumed to be taking place until 2050 for selected product groups (UNU-KEYs), capturing the main aspects of CE transition specific to the EEE sector.

These changes (with illustrations for selected UNU-KEYs) include:
1. Full or partial obsolescence in EEE POM by 2050
   » A near-complete drop in EEE POM of new video equipment, e.g. video recorders, DVD, Blu-ray, set-top boxes, and projectors (UNU-KEY 0404), driven by advances in smartphones and internet streaming
2. Stock saturation constraints per capita
   » Household electrical products such as fridges (UNU-KEY 0108) reaching market saturation in wealthier countries, when it does not make sense for an average household to have more than a certain number of items of a given product, even if they can afford them
3. Improved durability
   » A gradual increase in both designed and user-driven lifespans across most EEE products, including greater product reuse via second-hand markets (included in the lifespans implicitly)
4. Less hoarding
   » Products such as laptops (UNU-KEY 0303) and mobile phones (UNU-KEY 0306) either being used for longer periods, reused, or recycled instead of being hoarded, leading to reduced overall stock across households
5. More sharing
   » Products such as household tools (UNU-KEY 0601) being shared more, leading to higher product utilisation and the associated reduction in lifespan, as well as reduced overall stock across households

Further details on the CE and BaU scenarios, including a detailed set of assumptions for each UNU-KEY, are provided in the ANNEX 7.1.

The e-waste generated is calculated using the EEE POM and lifespan projections for both the BaU and CE scenarios. The e-waste recycling rate is calculated by dividing 'e-waste managed environmentally soundly' by 'e-waste generated'. The recycling rate for 2020 to 2050 is extrapolated from the present-day base value of 0.1% from Regional E-waste Monitor for the Arab States – 2021 (Iattoni et al. 2021). In the BaU scenario, the recycling rate is kept as a constant of 0.1%, while in the CE scenario, it is incrementally increased, linearly with time, from 0.1% to 100% in 2050.

The amounts of 'unmanaged e-waste' are calculated as 'e-waste generated' minus 'e-waste managed environmentally soundly'. The resulting effects of e-waste management are calculated using the material compositions per UNU-KEY category obtained from the ProSUM project (Huisman et al. 2017) for the year 2018 EEE POM. The environmental impacts of managing e-waste are based on the quantifications of 'e-waste managed environmentally soundly' and 'unmanaged e-waste' from The Global E-waste Monitor (Forti et al. 2020).

TABLE 2: **E-waste projections under CE and BaU scenario**

PARAMETER	1980-2020	2020-2050 BAU SCENARIO	CE SCENARIO
EEE POM	Country-level and product-level (54 UNU-KEY) data was taken from the Regional E-waste Monitor for the Arab States – 2021 (Iattoni et al. 2021). Country-level solar photovoltaic data was downloaded from IRENA.	Country-level SSP projections for GDP PPP and population were downloaded from the IIASA SSP Database. These were adjusted using the World Bank data for historic country-level GDP PPP and population in West Asia. Further details are provided in the References section and in section 2.3 POM projections were derived using country-level empirical correlations between UNU-KEYs and GDP PPP, as described in The Global E-waste Monitor (Forti, et al. 2020)	Same as the BaU scenario, except that per UNU-KEYs, additional changes were built in for full or partial obsolescence in EEE POM by 2050, stock saturation constraints, improved durability, less hoarding, and more sharing. The changes result in less EEE POM than in the BaU scenario for most UNU-KEYs. Further details ae provided in ANNEX 7.1
Lifespan	UNU-KEY-level data for product lifespans was taken from the Regional E-waste Monitor for the Arab States (Iattoni et al. 2021)		Products become more durable (30% longer lifespans) and/or get utilised more (leading to 15% shorter lifespans)
E-waste Generated	Calculated from above datasets		
E-waste recycling rate	Taken from the Regional E-waste Monitor for the Arab States (Iattoni et al. 2021)	The recycling rate for 2019 (0.1%) remained constant	Incremental increase from 0.1 to 100% collection and recycling rate for all countries

2.3 Socioeconomic Pathways Underpinning the BaU and CE Scenarios

The BaU and CE projections for PM and e-waste have been calculated using the Shared Socioeconomic Pathways (SSPs) for GDP PPP, population, technology, energy, land use, and other socioeconomic indicators, which were developed by IPCC to perform climate change and broader sustainability assessments (Riahi et al. 2017). The SSPs capture a range of plausible world futures and include multiple underlying trends that both characterise and affect the crucial aspects of humanity's development, including how material goods are being consumed and recycled.

The plausible futures described by the SSPs range according to sub-national and international levels of cooperation, competition, government regulation, wealth distribution, education, urbanisation, technological development, energy use, land use, and so on. We note that gender only features in the modelled age pyramids explicitly, though both the GDP and population projections implicitly depend on the assumed levels of emancipation of women in the underlying OECD macroeconomic models from which these projections have been derived (Riahi et al. 2017).

In this report, we use the SSP projections for GDP PPP and population individually in each West Asian country in order to explore the effects of long-term socioeconomic changes on EEE POM and e-waste generated in the region out to 2050.

For both the BaU and CE scenarios, the three most contrastive SSP scenarios are shortlisted, leading to a spread of the EEE POM and e-waste outcomes:
- SSP1, which provides medium-level projections for both GDP PPP and population, with the underlying drivers being associated with a broad sustainability and CE transition across much of the economy and society
- SSP3, which represents a world with high population growth, regional rivalries, material-intensive consumption, and sluggish economic development across the board
- SSP5, which is characterised by rapid economic growth, fast technological progress, high energy and resource consumption, and moderate population increases

Further information on the SSP scenarios, including the underlying SSP narratives, is provided in ANNEX 7.5.

2.4 Projections for Solar Photovoltaic Panels

Solar photovoltaic panels form a relatively recent but a fast growing stream of EEE, and though they are not yet generating considerable quantities of e-waste, they are currently being placed on the market in large quantities and with accelerating rates (Forti et al. 2020). Modelling future growth in photovoltaic panels among EEE POM is difficult due to rapidly evolving economic and geopolitical conditions underpinning climate change mitigation. In this report, we use the solar photovoltaic projections from the energy transition component of the SSP scenarios out to 2050 as a basis, adjusting them according to trends in West Asia from recent history (dataset of the International Renewable Energy Agency), combined with the 2019 World Energy Outlook photovoltaic scenarios for West Asia by the International Energy Agency. There is a considerable difference in the projected photovoltaic capacity under the SSP1-19 pathway compatible with the 1.5C target from the Paris Agreement, and all other SSP pathways, such as SSP2-34, SSP3-34, SSP4-26, and SSP5-60 (the suffixes in the scenario names represent target anthropogenic radiative forcing levels in 2100). Our adjusted photovoltaic projections broadly capture the differences in the underpinning SSP scenarios for solar photovoltaic installations, while also being aligned both with the relevant historic data and the IEA projections for West Asia. Further information on the photovoltaic projections developed in this report is provided in ANNEX 7.4.

The projected annual installed photovoltaic capacities for each scenario in each West Asian country have been converted to EEE POM by calculating the annual changes of the cumulative installed capacity. The changes were converted to EEE POM using recent global statistics on average output and weight of a single photovoltaic panel (Forti et al. 2020). In this report, the latest values – of approximately 300 W and 20 kg per panel – were extrapolated to 2050, assuming that the bulk of the efficiency gains in photovoltaics had already taken place over the past 20 years. The photovoltaic lifespans were modelled based on the latest e-waste data from the EU (Van Straalen et al. 2016). The datasets are allocated to UNU-KEY 0002 Photovoltaic Panels (incl. inverters).
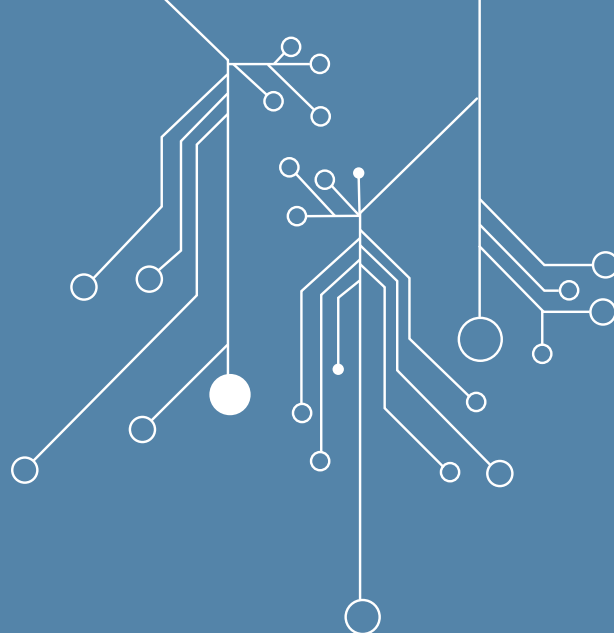
2050 PROJECTIONS FOR EEE POM AND E-WASTE GENERATION/ MANAGEMENT IN WEST ASIA
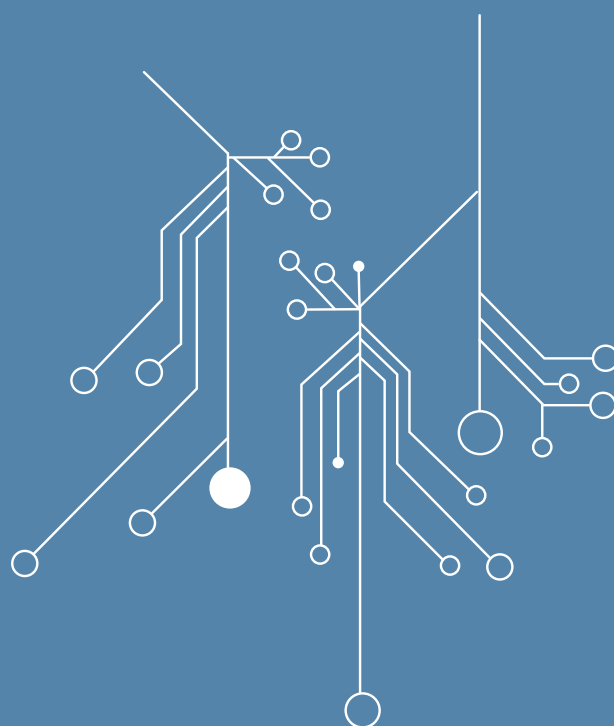
3. Projections for EEE POM and E-waste Generation/Management in West Asia

This report considers two contrasting scenarios in the EEE sector, both projected to 2050, for long-term e-waste generation and management in the West Asia region: a BaU scenario with current EEE consumption and disposal patterns and a CE scenario of improved EEE durability, sharing, reuse, and recycling.

3.1 Regional Overview

The scenarios' comparative effects on the totals are presented in the figures below. Figure 3 illustrates projections for EEE POM in the West Asia region under the BaU and CE scenarios. Under the BaU scenario, the amount of EEE POM is projected to steadily increase from 2.2 Mt in 2020 to between 4.8 to 7.5 Mt in 2050 (the range corresponds to variations in projected economic and demographic data). The CE scenario in the EEE sector has a noticeably stronger effect on EEE POM in the long term, reaching 3.1 to 5.6 Mt in 2025, which equates to 1.7 Mt to 2.4 Mt less in 2050 than in BaU conditions. In fact, under the CE transition pathway, the EEE POM's slope decreases in the 2040s, while the population still has access to and makes use of the same functionality that newer EEE can offer under the BaU pathway. This is achieved through more reuse and repair, more sharing, and longer lifespans of certain types of equipment.
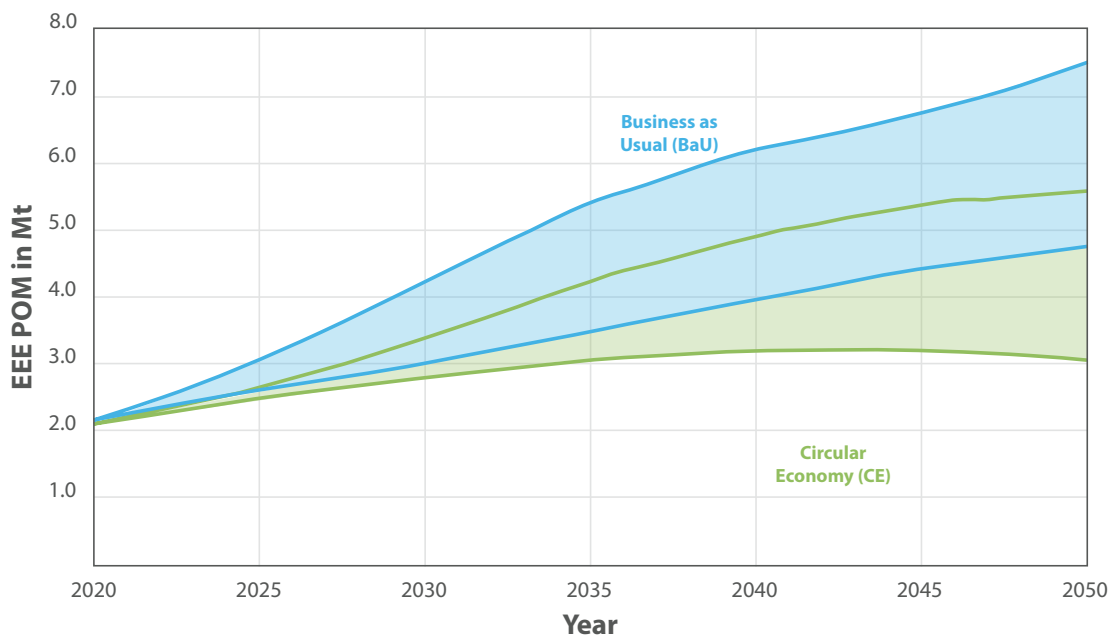
FIGURE 3: EEE POM (millions of tonnes per year) for the West Asia region, projected to 2050 for the BaU (blue) and CE (green) scenarios. The range corresponds to variations in projected economic and demographic data.

Figure 4 shows the resulting projections for e-waste generated out to 2050. Contrastingly, the e-waste generated for the time horizon considered shows a delayed response to the CE transition, generating between 3.3 and 3.9 Mt of e-waste in the BaU scenario in 2050. In the CE scenario, 2.9 Mt to 3.4 Mt of e-waste is generated in 2050, which is 0.4-0.5 Mt less than in the BaU scenario (as before, the range corresponds to variations in projected economic and demographic data). It is expected that the CE effects will be more pronounced in e-waste generated in the latter parts of the century, should assumed CE trends continue, though it is difficult to justify such long-term extrapolations due to the high levels of uncertainty involved. On the other hand, the e-waste generation in the next two to three decades has been partly predetermined by historic EEE POM to date, as well as the near-term POM projections (for 2020-2030) that are showing sustained EEE POM growth even in the CE pathway.

Supplementary data on the detailed modelling is provided in ANNEX 7.2 to 7.4. The projections per country are provided in ANNEX 7.7.

FIGURE 4: E-waste generated (in millions of tonnes annually) for the West Asia region, projected to 2050 for the BaU (blue) and CE (green) scenarios. The spread represents projected variations for economy and population.

Figure 5 shows the projected effects of the BaU and CE scenarios for unmanaged e-waste in the West Asia region. The variations in the underlying economic and demographic conditions cause a spread in the outcomes (illustrated in the bandwidth), but have a relatively small influence on the e-waste management outcomes. Focusing directly on increasing collection rates in the CE scenario, on the other hand, has the strongest effect on reducing unmanaged e-waste and thus needs the most attention. Shifting consumer behaviour and technology toward a CE model provides another important contribution to reduction of the unmanaged e-waste.

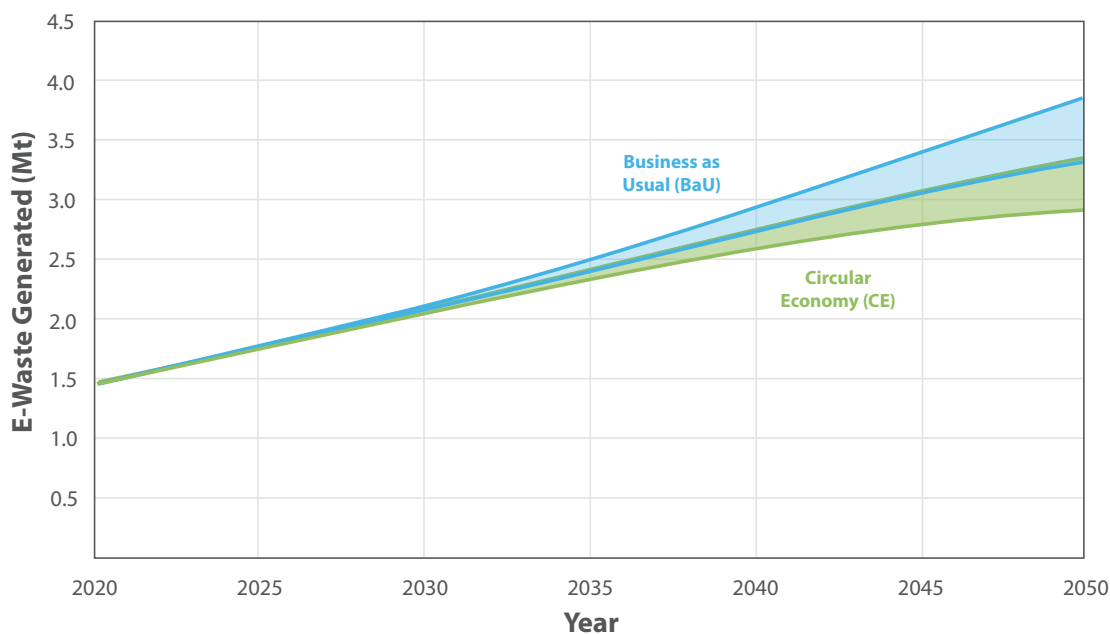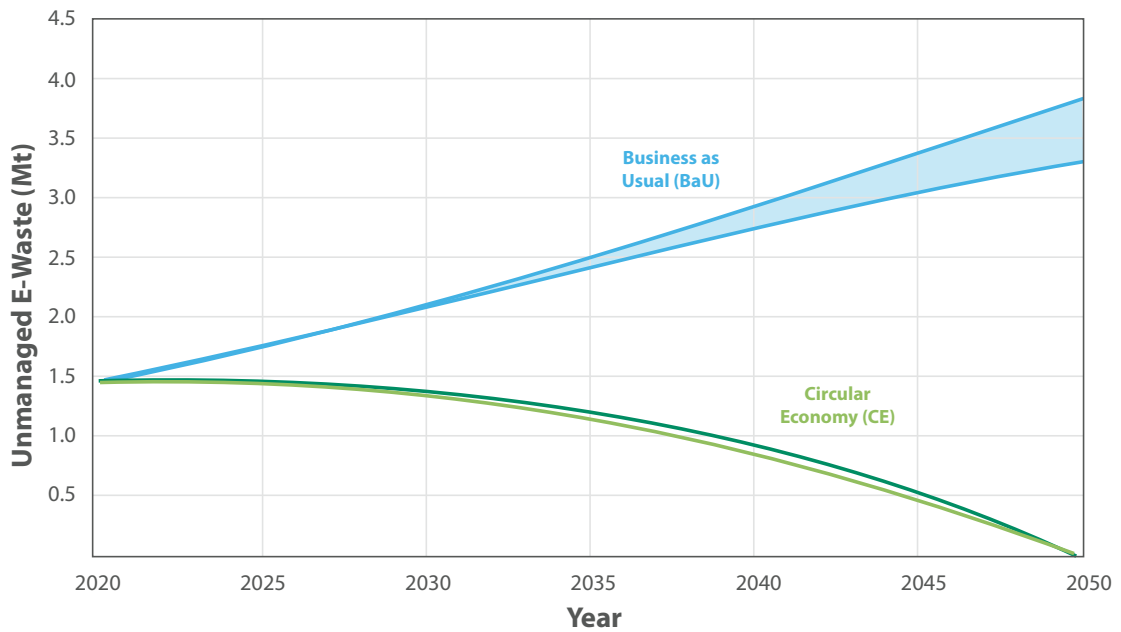**FIGURE 5:** Unmanaged e-waste (in millions of tonnes per year) for the West Asia region, projected to 2050 for the BaU (blue) and CE (green) scenarios. The spread represents projected variations for economy and population.

3.2 Overview of E-waste Categories

The breakdown of e-waste generated into six broad e-waste categories (in line with current global e-waste statistics guidelines, and an additional split for photovoltaic panels) shows that the largest share of e-waste is projected for small equipment (33% of the weight in 2050), followed by large equipment (24% of the weight), temperature exchange equipment (23%), small IT and telecommunication equipment (7%), photovoltaic panels (6%), screens and monitors (6%), and lamps (1%). Table 3 provides a summary of the average annual growth rates for e-waste generated between 2020 and 2050 for each category.

Of the average annual growth rates, as shown in Table 3, the rates for photovoltaic panels stand out in both the CE and BaU scenarios. This is because photovoltaic panels barely exist in the e-waste streams in 2020 and are expected to rapidly increase with the ongoing transition to renewable energy. Total e-waste generated (Table 3, bottom row) is projected to grow at average annual rates of 5.2% for the BaU scenario and 4.0% under the CE pathway for the EEE sector (average figures across the range of economic and demographic evolutions considered). All e-waste categories show consistently smaller annual growth rates in e-waste generated under the CE consumer behaviour and technology scenario for the EEE sector than in the BaU scenario. On the whole, the CE transition in the EEE sector reduces annual growth rates in e-waste generated by roughly 1% relative to BaU, though small IT equipment shows a much smaller drop of 0.3% (see above), while both lamps and small equipment undergo larger-than-average drops of 1.6% and 1.4%, respectively, in the projected e-waste streams.

TABLE 3: Average linear growth rates per annum between 2020 and 2050 for e-waste generated (mean values over the economic and demographic projections), shown separately for six EEE categories. The results are further broken down in the BaU and CE scenarios.

	CATEGORY	EXAMPLE OF PRODUCTS IN CATEGORY	BaU	CE
I	Temperature Exchange Equipment	fridges, freezers, air conditioners, and heat pumps	5.9%	4.8%
II	Screens and Monitors	liquid crystal displays (LCD) and light-emitting diode (LED) televisions and monitors, laptops, and tablets	1.8%	1.0%
III	Lamps	LED lamps, high-intensity discharge lamps, and compact and straight tube fluorescent lamps	4.3%	2.7%
IVa	Large Equipment (excl. photovoltaic panels)	dishwashers, washing machines, ovens and central heating systems, and large printing systems	4.9%	4.3%
IVb	Photovoltaic Panels	photovoltaic panels and invertors	9,500%	6,700%
V	Small Equipment	microwaves, grills and toasters, personal care products, speakers, cameras, audio sets, and headphones, as well as toys, household tools, and medical and monitoring systems	4.8%	3.4%
VI	Small IT and Telecommunication Equipment	desktop personal computers, printers, mobile phones, cordless phones, keyboards, routers, and consoles	3.3%	3.0%
	Total		**5.2%**	**4.0%**

3.3 High-income Countries Versus Middle- and Low-income Countries

Figures 6 and 7 show the breakdown of the projected EEE POM and e-waste generated for both high-income and low- and middle-income countries in the West Asia region. The high-income countries include: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. The high-income countries in West Asia also form the so-called Cooperation Council for the Arab States of the Gulf. The middle- and low-income countries and territories include: Iraq, Jordan, Lebanon, Syrian Arab Republic, Yemen, and the State of Palestine.

As expected, high-income countries are characterised by higher levels of EEE POM and e-waste generated, in the past as well as projected to 2050. However, POM tends to level off and decrease in the 2040s in the high-income countries under the CE transition assumptions for the EEE sector. By contrast, middle- and lower-income countries show a more persistent growth, both in EEE POM and e-waste generated – trends driven by economic development and population growth. Based on these trends, middle- and lower-income countries in West Asia could overtake higher-income countries in terms of the total quantity of POM and e-waste in the latter parts of the century. This transition could occur as early as in the 2040s for POM if high-income countries follow the CE transition for the EEE sector, while the middle- and low-income countries remain on the BaU pathway (Figure 6).
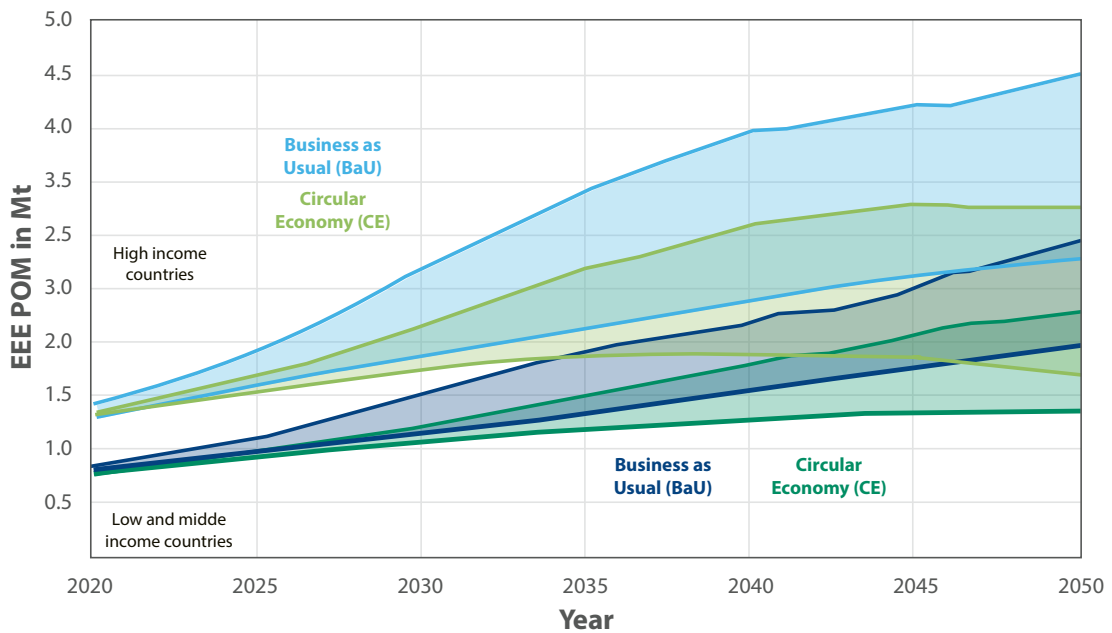
FIGURE 6: EEE POM (millions of tonnes per year) for both high- and middle-/low-income country groups for the West Asia region, projected to 2050 for both the BaU (blue) and CE (green) scenarios. The spread represents variations for economy and population.
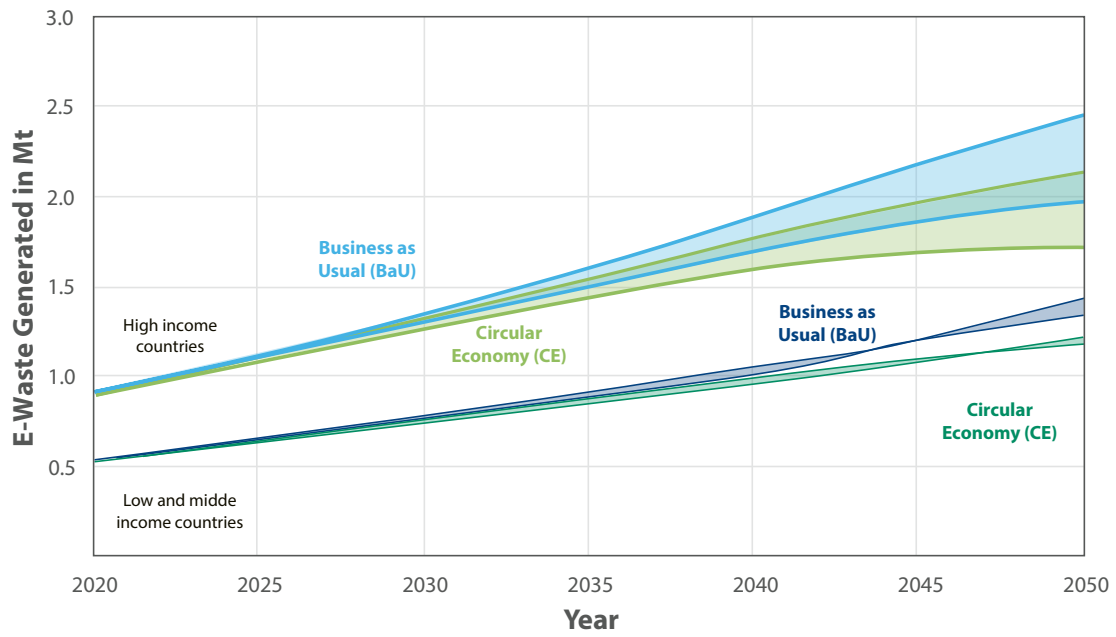
FIGURE 7: E-waste generated (millions of tonnes per year) for high- and middle-/low-income country groups in the West Asia region, projected to 2050 for the BaU (blue) and CE (green) scenarios. The spread represents projected variations for economy and population.
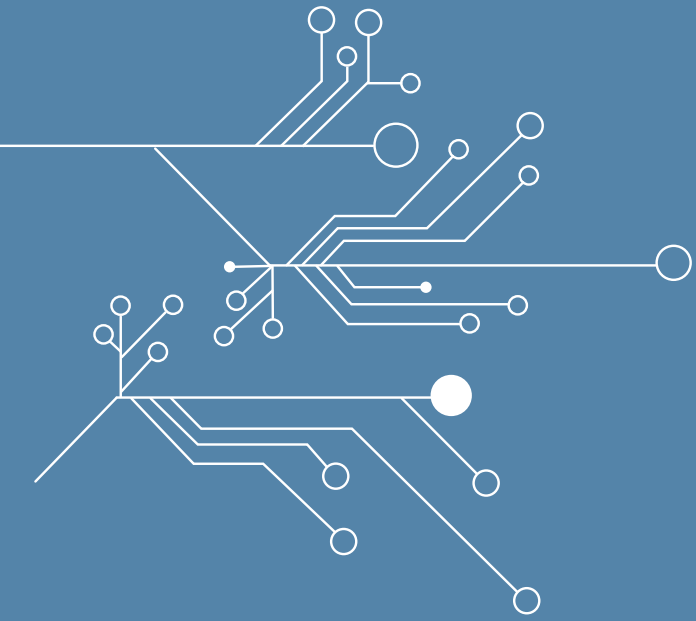
EFFECTS OF A CIRCULAR ECONOMY TRANSITION ON E-WASTE IN WEST ASIA
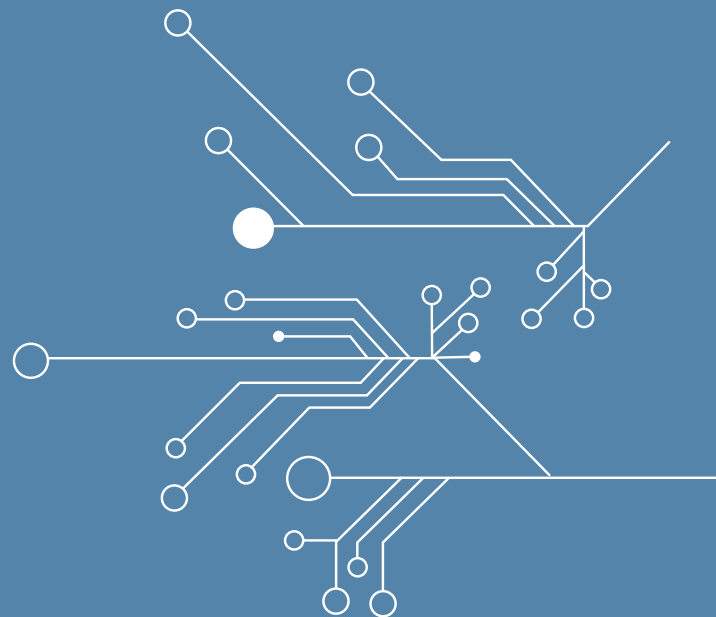
4. Effects of a Circular Economy Transition on E-waste in West Asia

The results above demonstrate the challenges of managing e-waste in an economically diverse West Asia region. Some underlying trends, such as economic and population growth in the poorer countries, are not the responsibility of e-waste management policies, but they have a non-negligible effect on the projected e-waste outcomes over the next three decades. The choices made specifically with respect to e-waste will undoubtedly have significant implications for the environment, resource efficiency, human health, and a broader social context in West Asia in the long run. The associated environmental, health, and resource recovery impacts are further quantified in this section.

Figure 8 shows the cumulative amount of managed and unmanaged e-waste (in Mt) in the current BaU pathways of low collection rates and in the CE behaviour and technology change for the EEE sector. A cumulative amount of e-waste of between 39 and 43 Mt is projected to be managed in West Asia from 2020 to 2050 if the 100% e-waste collection rate is met by 2050 (linearly extrapolated from the 2020 collection rate of 0.1%). The cumulative impact of mitigated emissions of hazardous substances and greenhouse gases and the cumulative potential of recovered resources is shown in Figure 8. The projected recovered resources across the West Asia region include approximately 130 tonnes of gold, 5 kt of rare earth metals, 17 Mt of iron and steel, 1.5 Mt of copper, and 2.6 Mt of aluminium. Likewise, e-waste also contains hazardous materials, and under the pathway considered in this section, a larger proportion of these materials will be managed in an environmentally sound manner, leading to estimated mitigated emissions of up to 6 t of mercury, 60 t of cadmium, 11 kt of lead, 19 kt of brominated flame retardants, and 53 Mt CO_2e of greenhouse gases (from refrigerants).

BaU scenario Cumulative 2020-2050

75 to 79 Mt
Unmanaged e-waste

0.1 Mt
Managed e-waste

CE scenario Cumulative 2020-2050

31 to 32 Mt
Unmanaged e-waste

39 to 43 Mt
Managed e-waste

Mitigated emissions
6 t Mercury
60 t Cadmium
11 kt lead
19 kt Brominated Flame Retardants
53 Mt CO_2e Greenhouse gas emissions

Recovered
130 t Gold
5 kt Rare Earth Materials
17 Mt Iron and Steel
1.5 Mt Copper
2.6 Mt Aluminum
11 kt Cobalt

FIGURE 8: Cumulative managed vs unmanaged e-waste between 2020 and 2050 (Mt) under the BaU and CE scenarios. The ranges correspond to projected variations for economy and population. Mitigated emissions and recovered resources between 2020 and 2050 are shown for the CE pathway.

The e-waste recycling sector is not currently a significant employer in West Asia, with most e-waste is either landfilled or taken care of by the informal sector. Informal recycling generally has a negative social impact. For instance, typical working times were found to be more than 72 hours a week, the workers are not entitled to any social welfare (Umair et al. 2015), and the jobs are performed by unskilled labourers, women, and children, with negative consequences both for human health and the environment (Forti et al. 2017). Shifting the informal e-waste management practices to formal recycling will likely improve working conditions, such as 8-hour workdays at formal recycling sites, and reduced negative environmental impacts and health effects compared to workers at informal sites (Julander et al. 2014).

As well, the shift toward a circular economy will have a positive effect on the quantity of the jobs created. In South Africa, for instance, there are currently an estimated 25 full-time equivalent recycling jobs per 1,000 t handled, and the sector has the potential to increase this number as more recycled e-waste is reintroduced back into the value chain (Lydall et al. 2017). Using this number, around 90,000 FTE (full-time equivalent) jobs would be created in 2050. In Ireland, where a highly efficient e-waste pre-treatment facility exists, 1 FTE job is required for managing either 1,967 t of large household devices or 13,407 t of cooling and freezing equipment (McMahon et al. 2021). These are jobs both in the e-waste pre-treatment phase, such as unloading, manual dismantling, depollution, baling, compacting and loading, and working with the final treatment stage. Managing all e-waste in such highly efficient pre-treatment facilities would generate just 2,500 FTE jobs in similar pre-treatment facilities in 2050 across West Asia, based on the projected amounts of e-waste generated in the region. This excludes the jobs for collecting the e-waste and transferring it to pre-treatment facilities. Therefore, the average between the South African (90,000 FTE) outcome and the highly mechanical outcome is taken, thus equating to roughly 45,000 FTE jobs in e-waste management.

The social impacts of repairing and refurbishing used EEE products have been scientifically researched even less, and it is very unclear how the efficiencies of these processes will develop over time across multiple product categories. However, applying internal statistics from the RREUSE network suggests that social enterprises working in e-waste refurbishment are likely to create between 15 and 110 jobs and training opportunities per 1,000 tonnes of repaired products processed (RREUSE 2015). Averaging these two figures, we estimate that repairing and refurbishing used EEE products could generate more than 180,000 FTE jobs by 2050, given the projected quantity of around 3 Mt of e-waste being generated across West Asia by 2050 (Figure 2). The total job creation, therefore, is estimated to be roughly 225,000 FTE jobs (when rounding up the e-waste management estimate and the repair estimate).

Summing up, our results demonstrate the challenges of managing e-waste in an economically diverse region such as West Asia. Some underlying trends, such as economic and population growth in the poorer countries, are not the responsibility of e-waste management policies, but they have a non-negligible effect on the projected e-waste outcomes over the next three decades, especially when it comes to solar photovoltaic panels. Compared to the underlying socioeconomic trends, changes to consumer behaviour and technological trends in the EEE sector generally have a stronger effect on the amount of EEE POM and a similar effect on the amount of e-waste generated. Richer countries show a degree of saturation of EEE POM in 2040s, especially under a CE transition in the EEE sector, but they are still characterised by a continued growth in e-waste generated over the next three decades and maintain high levels of consumption and e-waste per capita. Ultimately, collection rates affect the amount of unmanaged waste more than other factors at play (Figure 5).

As such, a considerable effort must be made in scaling up collection and recycling facilities for e-waste and raising consumer awareness of the issue across the whole of the West Asia region. Much stronger targets, focused on reaching 100% collection rates by 2050, are the only way to flatten the growing unmanaged e-waste curve. In some ways, the long-term 100% e-waste collection target is equivalent to the pledges for reaching the net zero carbon emissions target by 2050 that have been made recently by several high-income countries. While richer nations might have more resources and stronger institutions to drive the required increases in collection rates, the poorer countries, many of which have been engulfed in long-term wars and political instability, may struggle to implement the necessary measures. Overall, the e-waste collection outlook for the West Asia region remains uncertain and concerning.

FIVE
POLICY RECOMMENDATIONS

5. Policy Recommendations

Waste prevention policies of the European Commission refer to 'measures taken before a substance, material or product has become waste, that reduce: (a) the quantity of waste, including through the reuse of products or the extension of the life span of products; (b) the adverse impacts of the generated waste on the environment and human health; or (c) the content of harmful substances in materials and products' (European Commission 2008). Therefore, policy should tackle both the quantity of e-waste generated (quantitative prevention) and the e-waste's toxicity (qualitative prevention), which can prove more complicated to manage or regulate (McCann and Wittmann 2015). Public authorities can choose to: (i) ban the use of toxic substances in EEE, (ii) encourage or oblige manufacturers to provide clear information to the consumer regarding the characteristics and environmental performance of a product, or on how to minimise the environmental impact when using a product, and (iii) promote research and development to enable the private sector to design and produce less toxic, more recyclable, and less wasteful products and technologies.

Policymakers also have a number of potential options for encouraging improved separation of e-waste, which leads to greater e-waste prevention through reuse and supports better recycling outcomes. The best option for a given country in West Asia depends on the information available, the maturity of the system, its socioeconomic setting and complexity, and the current availability of recycling infrastructure. Specific measures must be put in place to ensure that women and socially disadvantaged groups are included in stakeholder engagements, and sex-disaggregated data may be useful, as it provides an evidence base supporting the formulation of successful gender-responsive policies (UNEP - International Environmental Technology Centre and Global Resource Information Database-Arenda [UNEP-IETC and GRID-Arendal] 2019). Such an approach also requires robust market data as well as sex-disaggregated data prior to setting any target for a collection system. A successful approach for establishing a successful collection system should be developed collectively with all stakeholders and continuously monitored, improved, and adjusted, when necessary.

Another hurdle for system designers and policymakers is to understand how to measure whether the target has been achieved or not. It is important here to also reflect the channels that fall outside of the e-waste recycling and producer systems, such as landfilling and informal e-waste treatment, which is by far most prevalent in West Asia, with a collection rate of just 0.1%. One way in dropping off e-waste for free is through municipal waste collection centres. Though the municipality may incur costs for providing the service, the costs can be offset by raising necessary funds from producers through regulatory systems or consumers, either at point of purchase or point of disposal (McCann and Wittmann 2015). Another policy tool that has proved effective in many jurisdictions is to make the actors who are responsible for selling products, such as distributors and retailers, financially responsible for their role in the collection system.

State-of-the-art recycling technologies are recycling operations that employ the best-available technology in the industry that have been proven to meet environmental legislation, that have high resource efficiency as obtained via scientifically proven mass balances, and whose by- and waste products' final fate are clearly shown (UNEP & StEP Initiative 2009). Refined materials can then be utilised again in the production of new goods. Policy in West Asia and elsewhere must choose to improve practices from available options, from manual to state-of-the art recycling processes. So, it must first identify the local demand for recyclable materials and the technical requirements necessary for those materials. For end-processors, recyclable materials must be: (i) as pure as possible, which implies that they should have been

well-separated from other materials, (ii) conditioned in a way that they can easily be transported and used in the manufacturing industry, (iii) sent in large quantities, which also reduces the cost of being shipped in containers, and (iv) usually presented as non-shredded parts. But these technical factors must also consider economic factors because not all are technically or economically feasible.

Policy has also a role to play in responding to the continuous change in the composition of EEE. The policy must support research on the potential hazards associated with new materials and substances that can find their way into EEE. Public authorities must then alert the private sector, recyclers, and consumers regarding the associated issues.

E-waste recycling is currently a globalised sector, so policy must support the decision-making in an international arena. As such, it is advisable for many countries in West Asia to prioritise the following investments: (i) developing and scaling up the repair and reuse sector, so that the equipment provides benefits to as many consumers as possible while creating local jobs; (ii) proper training on manual dismantling techniques and follow-up with informal and small-scale operators on the use of these techniques; (iii) networking and collaboration with the end-processors as potential buyers of materials recovered from manual dismantling; and (iv) support for export processes and related administrative work in order to create maximum value recovery and financial flow back to the country from end-processors.

Until recently, most public policies and private initiatives in developing countries, including in West Asia, have focused on attracting a flux of second-hand equipment for the purpose of refurbishing it and selling it on their national markets. However, as this study also illustrates, e-waste streams are increasing quickly, so it has become urgent for countries to work on solutions for managing them – such as raising awareness and training local recyclers on environmentally safe collection and dismantling practices.

STEPWISE APPROACH FOR A COUNTRY

6. Stepwise Approach for a Country

Considering that no one-size-fits-all solution exists for West Asia or any other global region, these recommendations, developed in 2016 (when UNU hosted the Solving the E-waste Problem [StEP] Initiative), are guiding elements that should be tailored and implemented, with local conditions taken into account:

1. **Establish a clear legal framework for e-waste collection and recycling.**
   At a minimum, e-waste legislation must include the following elements:
   - A clear definition of the role of the local municipality and the national government
   - A clear definition of who is responsible for organising the collection and recycling
   - A clear definition of who is responsible for financing the e-waste collection and recycling
   - National alignment on definitions of e-waste
   - A permitting and licensing structure for e-waste collectors and recyclers
   - A clear definition of 'producer' if the system is based on the so-called 'extended producer responsibility' (EPR) principle. Without such a clear definition, no company will feel obliged to comply, and the fair enforcement of legal provisions across the industry will be more difficult (see Principle 2)
   - Allocation of collection and recycling obligations between producers: legislation needs to describe how the obligations will be divided among all companies, and it must describe how a producer knows how much e-waste it needs to collect and recycle. For instance, market share of sales can be used to determine how much of the total waste needs to be attributed to one producer and recycled (e.g. a 10 per cent market share of sales would mean 10 per cent of the e-waste needs to be collected and recycled by one producer). A decision can also be made dictating that recycling fees should be paid for each product placed on the market
   - A description of how companies shall register as 'producers' and document their compliance status to ensure that the legislation can be enforced
   - A clear description of the goals and measurable targets of the legislation so that it is possible to assess whether or not stakeholders are compliant
   - An inclusion of the licensing and/or certification of e-waste collection and recycling facilities when relevant for licensing and operating industrial facilities

2. **Introduce extended producer responsibility (EPR) to ensure that producers finance the collection and recycling of e-waste.**
   There are three primary objectives of the EPR principle:
   - Manufacturers shall be incentivised to improve the environmental design of their products and the environmental performance of supplying those products.
   - Products should achieve a high utilisation rate.
   - Materials should be preserved through effective and environmentally-sound collection, treatment, reuse and recycling.

   Under an EPR regime, responsibility can be assigned either individually, where producers are responsible for their own products, or collectively, where producers in the same product type or category fulfil the responsibility for EoL management together.

There are a variety of possible interventions that a government can make to implement EPR principles, and mandatorylegislation is not always the best way to proceed.

Any system should seek to create a level playing field by promoting effective standards through the licensing and permitting of stakeholders. This helps to ensure that there is fair competition among producers, as well as between recyclers.

Although there are clear examples of successful business-led voluntary programmes, this represents the exception rather than the rule. In addition, there remains a strong case for governments to influence businesses to operate in a more environmentally-sensitive and beneficial direction.

3. **Enforce legislation for all stakeholders and strengthen monitoring, statistics, and compliance mechanisms across the country to ensure a level playing field for all, including socially disadvantaged groups and women.**

Enforcement will ensure that all stakeholders (e.g. collectors, recyclers, and producers) meet the requirements of the legislation so that no company can financially benefit from not meeting the requirements. Enforcement will help create a level playing field for all companies and improve working conditions in the informal and formal sectors, including for socially disadvantaged groups and women who have unequal access to jobs and other opportunities for economic empowerment. Such enforcement includes setting up annual e-waste monitoring, establishing targets on e-waste collection in shifting to a circular economy, and reporting official statistics on e-waste.

4. **Create favourable investment conditions for experienced recyclers to bring the required technical expertise to the country, targeting both female and male recyclers.**

Design and implementation of favourable investment conditions within a country can trigger growth in domestic recycling technology. The new recycling technology will support treatment of WEEE as close to the source as possible, creating jobs and supporting national environmental goals.

Because investing in recycling technology that follows environmental standards may require research and development or other types of funding, it is essential that investors be provided with favourable and stable market conditions, including fair competition among peers, as opposed to unfair competition from informal players.

The investments should ensure even distribution targeting both female and male recyclers because once labour is formalised, waste management could become dominated by male recyclers. Taking affirmative action by setting quotas for female recyclers is encouraged.

5. **Create a licensing system or encourage certification via international standards for collection and recycling.**

The core aim of e-waste policy is to protect the environment and effectively recover natural resources. The application of a simple and effective licensing or certification system is key for ensuring that all collectors and recyclers are known to the authorities and appropriately authorised to carry out specific activities.

The licensing system should appropriately address the environmental and health risks associated with the activities undertaken. Similarly, it should reflect the respective country's capacity to handle such a system in terms of enforcement, institutional capacities, training, etc. A phased development of the licensing system should be developed.

6. **Develop a wide network of collection point or collectors to separately collect all e-waste generated at the source.**

In many countries without legislation governing e-waste management, an informal and unregulated network of collectors and recyclers exists. It is important for governments to develop gender-responsive guidelines or regulations that identify specific activities as either informal or formal and that define requirements for licensed recyclers. If an informal collection system exists, it should be used to collect e-waste, and it must be ensured that e-waste is sent to licensed recyclers through incentives. Informal collection systems should acknowledge women's contributions at the household level, as such acknowledgments have not yet clearly existed (UNEP-IETC and GRID-Arendal 2019). If formal collection of waste exists from the municipality, a wide network of collection (both drop-off and door-to-door) should be developed for separating e-waste from the other municipal wastes. In addition, a collection of e-waste through retailers should be started, small e-waste items should be collected through places that people often visit, such as supermarkets. To move the waste sector forward, equal opportunities and recognition for both women and men are key in both formal and informal waste collection systems.

7. **When no local end-processing facilities exist for an e-waste item, ensure good and easy access to international licensed treatment facilities.**

Countries often develop their own pre-processing facilities for tasks such as separating the basic material parts (pre-treatment). To some extent, the countries also perform recycling (end-treatment) of materials, like plastics and steel, that can efficiently be recycled with relatively low technological investment. After recycling, these materials can be traded as raw material, domestically or internationally. Recovery of precious metals – such as those from printed circuit boards or cobalt from batteries, as well as less valuable but potentially toxic materials, such as cathode ray tube glass and flame-retardant plastics – requires significant investment. Plants usually process a large amount of such materials to achieve economies of scale; these can only operate at a profit by processing high volumes of the material, which is impossible on the national level. This means that globally, only a handful of these recycling facilities are necessary to provide these specific recycling and resource recovery solutions. In order for these systems to run efficiently and economically, it is essential that countries allow specific material parts to be exported and imported to these facilities.

8. **Ensure that costs for running the system are transparent and stimulate competition in the collection and recycling system in order to drive cost effectiveness.**

Transparency regarding the actual recycling costs should be pursued in order to increase the consumers' and the general public's awareness of the financial requirements needed for proper e-waste management. Fair competition between logistics providers and recyclers should be established to ensure the system's long-term cost effectiveness. One of the key elements that should not be decoupled from the cost effectiveness is the establishment and enforcement of minimum quality standards; the rationale for lowering processing costs should never be relaxing control over the disposal of hazardous parts or the standards protecting the environment or worker health. Additionally, women should be enrolled in these improved opportunities in waste management and recycling as one of the means for reducing the existing gender gap. Affirmative action such as setting gender-based quotas and adopting gender-responsive budgets in waste management and recycling is one way of addressing this issue (United Nations Environment Programme [UNEP] 2019)

9. **Ensure that all stakeholders involved in e-waste collection and recycling are aware of the potential gender-differentiated impacts on the environment and human health, as well as possible approaches to the environmentally sound treatment of e-waste.**

It is important to ensure that all stakeholders (e-waste generators, collectors, recyclers, government, and financiers) are aware of the potential environmental and human health impacts of improper e-waste treatment, including gender-differentiated impacts. Research shows that due to their physiological differences, women and men are impacted differently following exposure to chemicals and waste, which can have critical effects with regard to susceptibility and disease development for both themselves and any children they carry and feed (Strategic Approach to International Chemicals Management [SAICM] 2018). The stakeholders must also understand the importance of addressing the problems and treating e-waste in a sound manner. Once legislation is in place, the stakeholders need to be aware of the health and safety implications so that they can understand the potential risks of improper handling techniques. This comprehension will help to ensure that generators and recyclers put in place safety standards that address the needs of women and men and comply with regulations. Further awareness of serious environmental threa ts will encourage proper e-waste handling by generators and collectors as well as sound management and disposal of hazardous materials by recyclers, and it will stimulate the development of cleaner technologies for managing these residues.

10. **Create targeted gender-differentiated awareness campaigns among consumers regarding a circular economy and its environmental benefits.**

Awareness and behavioural change toward circular behaviour, such as preferring repair and refurbishing over disposal, are essential for e-waste prevention and job generation and need to be facilitated through awareness campaigns. However, at some point in time, everything becomes waste, and this study shows that increasing collection rates has the strongest effect on reducing unmanaged e-waste, so this method calls for the most attention. All waste collection programmes begin with consumers (individual households or organisational entities), as consumers decide when and how to dispose of a product. Thus, it is critical that consumers decide to utilise licensed recycling facilities instead of sending their waste to landfills, substandard treatment, or incineration. The decision to send a product to a licensed recycler can be influenced by incentives and the awareness that recycling provides more environmental benefits than other disposal options. The consumer must also understand how to access the appropriate recycling streams. In some countries, awareness of the environmental benefits is high, but knowledge of how to participate or how to verify such a recycling solution is low. Therefore, it is very important that consumers are well-informed on the environmental benefits of recycling in order to ensure that they will support the system's creation and send products for licensed recycling when appropriate. As women are often tasked with waste management at the household level, it is crucial that messages tailored to their needs are created, as tailored messages are often a more effective and relatable way of communicating (UNEP-IETC and GRID-Arendal 2019) (Woroniuk et al. 1999).

SEVEN
ANNEX

7. ANNEX

7.1 Methodology for the CE Pathway

The circular economy (CE) pathway for consumer behaviour and technological changes in the EEE sector consists of the following five components:
• Full or partial obsolescence for certain products
• Saturation in stock per capita
• Increased durability
• Less hoarding
• More sharing

Obsolescence implies that new products on the market (POM) decrease to zero first, followed by both WEEE and stock per capita a few years later, in accordance with the product lifespans. In this report, however, we apply obsolescence targets in 2050 to POM, i.e. a 100% reduction in POM by 2050 relative to the 2050 baseline projection. For some products, it also appears sensible to prescribe a partial obsolescence as opposed to a full obsolescence. For example, UNU-KEY 0403 'Music Instruments, Radio, Hi-Fi (incl. audio sets)', may not disappear completely if some people still have musical instruments and hi fi sets. As such, we need to prescribe an appropriate reduction in POM by 2050, such as a 90% or 75% reduction relative to the corresponding 2050 baseline.

Some products such as refrigerators and washing machines are likely going to reach a market saturation constraint once most households have them. This constraint will likely need to be defined individually for each UNU-Key, where applicable, and expressed in terms of the actual stock per capita as opposed to relative stock changes (as in other examples below). The saturation constraint is expected to be relevant mostly in high-income countries, especially in high-growth and high-consumption scenarios, such as SSP5. Some middle- and even lower-income countries may also reach this constraint by 2050 under high-growth pathways. In this report, the saturation stock per capita values, when not obvious, are based on present-day stock figures from high-income countries taken from the latest Global E-Waste Monitor (Forti et al. 2020).

Improved durability implies longer lifespans across most products, achieved both through built-in longevity and consumer behaviour directed toward longer use and reuse. This trend would lead to less new products being placed on the market, assuming that the overall stock per capita remains the same.

The implications of reduced hoarding are more difficult to grasp, as the fates of discarded used EEE items could vary considerably (see, e.g., Sayers et al. 2020). The discarded items that shift either to second-hand use or hoarding have longer lifespans, with respect to e-waste generated. The items that shift either into recycling or residual waste have shorter lifespans. However, when items end up in second-hand use instead of hoarding due to behaviour change, there is no clear outcome for the lifespans. If one assumes that less hoarding fully translates into more second-hand use and that the characteristic product household residence times for both hoarding and second-hand use are similar, switching from hoarding to reuse may have little effect on the overall lifespan from products being placed on the market to them becoming e-waste. We follow this line of reasoning in our implementation of the reduced hoarding pathway by assuming that product lifespans are going to remain the same, as hoarding is fully substituted by second-hand use. We also make

an additional assumption that the overall stock (of both first- and second-hand items) is going to decrease, due to less hoarding. This implies a lower POM resulting from a greater reuse of older items as opposed to them being hoarded.

Finally, more sharing means reductions in stock per capita driven by reduced POM, but it is also likely to involve further reductions in lifespans, as the shared products get used more frequently, and their designed lifespan is exhausted sooner. As a starting point, we are going to assume that a certain percentage reduction in stock per capita through increased product sharing translates to the same percentage reduction in product lifespan.

The corresponding parametrisations for the five CE pathways described above are shown in Table 4 and Table 5 below. Apart from the POM obsolescence pathway, all other pathways involve making adjustments to the projected POM under a given SSP scenario in order to meet a certain stock per capita target in 2050. Two of the pathways – increased durability and more sharing – also involve gradual changes to product lifespans, with longer lifespans for increased durability and shorter lifespans for greater levels of sharing. The reduced hoarding pathway assumes that used items are more likely to end up in second-hand use than to be hoarded, with a net reduction in the total stock and comparable product lifespans.

The five pathways described above have been applied consecutively, one after the other, and separately for each UNU-KEY, each country in West Asia, and each SSP scenario, in line with the parametrisations in Table 5. The latter are assumed to be independent of the country, though the stock saturation pathway tends to be applicable only to high-income countries. The required adjustments to POM relative to the baseline projection under a given SSP, either directly prescribed as in the obsolescence pathway or tuned to the specified changes in stock per capita and product lifespans, are implemented as a quadratic function of time (t) between the base year (2019) and 2050:

$$POM_{adj}(t) = POM_{base}(t) \cdot \max\left(0, \left[1 - \alpha \cdot \left(\frac{t - 2019}{2050 - 2019}\right)^2\right]\right).$$

Here, POM_{base} (t) represents the baseline POM projections in a year under t in the BaU assumptions for the EEE sector, and α is the optimisation constant to be obtained from the required stock and lifespan constraints.

In the full obsolescence cases, marginal adjustments such as increased durability are still possible while the products are being phased out. Such situations are described by setting $\alpha = 1$ and introducing an extra linear multiplier for the adjusted POM projection, which serves to accelerate the phasing out of the products closer to 2050:

$$POM_{adj}(t) = POM_{base}(t) \cdot \max\left(0, \left[1 - \left(\frac{t - 2019}{2050 - 2019}\right)^2\right]\right) \cdot \left(\frac{2050 - t}{2050 - 2019}\right).$$

In all cases apart from the full or partial obsolescence where the expected 2050 POM levels are stated directly, the algorithm automatically finds the required adjustments to POM (parameter α in the first equation above) in order to hit the specified stock and lifespan targets by 2050.

The optimisation procedure is then applied consecutively for the five circular economy pathways introduced above, instead of being applied simultaneously for all of them. The combined optimisation results for the total POM, e-waste, and stock in West Asia – both in tonnes and products per capita – and their comparison to the business-as-usual (BaU) projections (i.e. maintaining current behaviour) are shown in Figure 7.

TABLE 4: **Parametrisation of the five Circular Economy (CE) consumer behaviour and technology pathways for the EEE sector, according to the corresponding changes in product lifespans, POM, and stock per capita.**

| CE PATHWAYS	LIFESPAN CHANGES	POM CHANGES	STOCK PER CAPITA CHANGES
FULL/PARTIAL OBSOLESCENCE	no changes	-100% (relative to baseline) by 2050 for full obsolescence, and -90% or -75% by 2050 for partial obsolescence	follows POM target
SATURATION CONSTRAINT	no changes	-W% by 2050 tuned to the relevant stock constraint	actual stock per capita value specified individually for each UNU key to which the constraint is applicable (e.g. 0.5 fridges per person)
IMPROVED DURABILITY	+30% by 2050	-W% by 2050 tuned to the relevant stock constraint	constant stock constraint
LESS HOARDING	no changes, assuming hoarding is replaced by second-hand use with negligible lifespan changes	-X% by 2050 tuned to constant stock constraint, and given increases in lifespan	-15% by 2050, assuming hoarding is replaced by second-hand use, but with overall stock being reduced
MORE SHARING	reduction in lifespan EQUAL to the prescribed change in stock (-15% by 2050)	-Z% by 2050 tuned to the prescribed change in stock (-15% by 2050)	-15% by 2050, tuned through POM reductions (Z), AND in line with the prescribed lifespan reductions (EQUAL to the stock reductions)

TABLE 5: Parametrisations of the five Circular Economy (CE) consumer behaviour and technology pathways for the EEE sector, formulated separately for each UNU-KEY, and the link of the UNU-KEYs to the e-waste categories

UNU KEY	OBSOLESCENCE POM TARGET RELATIVE	SATURATION STOCK PPI TARGET ABSOLUTE	IMPROVED DURABILITY FLAG	LESS HOARDING FLAG	MORE SHARING FLAG	DESCRIPTION OF UNU-KEY	BROAD E-WASTE CATEGORIES
0001	0		X			Central Heating (household-installed)	IV
0002			X			Photovoltaic Panels (incl. inverters)	IVb
0101			X			Professional Heating & Ventilation (excl. cooling equipment)	IVa
0102			X	X		Dishwashers	IVa
0103			X			Kitchen equipment (e.g. large furnaces, ovens, cooking equipment)	IVa
0104		0.4	X		X	Washing Machines (incl. combined dryers)	IVa
0105			X		X	Dryers (washer-dryers, centrifuges)	IVa
0106			X	X		Household Heating & Ventilation (e.g. hoods, ventilators, space heaters)	IVa
0108		0.7	X	X		Fridges (incl. combi-fridges)	I
0109			X	X		Freezers	I
0111			X	X		Air Conditioners (household-installed and portable)	I
0112			X	X		Other Cooling equipment (e.g. dehumidifiers, heat pump dryers)	I
0113			X			Professional Cooling equipment (e.g. large air conditioners, cooling displays)	I
0114			X	X		Microwaves (incl. combined, excl. grills)	V
0201			X	X		Other small household equipment (e.g. small ventilators, irons, clocks, adapters)	V
0202			X	X		Equipment for food preparation (e.g. toasters, grills, food processing units, frying pans)	V
0203			X	X		Small household equipment for hot water preparation (e.g. coffee, tea, water cookers)	V
0204		0.8	X	X		Vacuum Cleaners (excl. professional)	V
0205			X			Personal Care equipment (e.g. toothbrushes, hair dryers, razors)	V
0301			X	X		Small IT equipment (e.g. routers, mice, keyboards, external drives & accessories)	VI
0302	0.1		X			Desktop PCs (excl. monitors, accessories)	VI
0303			X	X	X	Laptops (incl. tablets)	II
0304			X		X	Printers (e.g. scanners, multi-functionals, faxes)	VI
0305	0		X	X		Telecommunication equipment (e.g. [cordless] phones, answering machines)	VI
0306		2	X			Mobile Phones (incl. smartphones, pagers)	VI
0307			X			Professional IT equipment (e.g. servers, r outers, data storage, copiers)	IVa
0308	0		X			Cathode Ray Tube Monitors	II
0309			X			Flat-Panel Display Monitors (LCD, LED)	II
0401			X			Small Consumer Electronics (e.g. headphones, remote controls)	V
0402	0		X			Portable Audio & Video (e.g. MP3, e-readers, car navigation)	V
0403	0.25		X			Musical Instruments, Radio, Hi-Fi (incl. audio sets)	V

UNU KEY	OBSOLES-CENCE POM TARGET RELATIVE	SATURATION STOCK PPI TARGET ABSOLUTE	IMPROVED DURABILITY FLAG	LESS HOARDING FLAG	MORE SHARING FLAG	DESCRIPTION OF UNU-KEY	BROAD E-WASTE CATEGORIES
0404	0.1		X			Video (e.g. Video recorders, DVD, Blu-Ray, set-top boxes) and projectors	V
0405			X	X		Speakers	V
0406	0		X			Cameras (e.g. camcorders, photo and digital still cameras)	V
0407	0		X			Cathode Ray Tube TVs	II
0408			X			Flat-Panel Display TVs (LCD, LED, Plasma)	II
0501			X			Small lighting equipment (excl. LED and incandescent)	V
0502	0		X			Compact Fluorescent Lamps (incl. retrofit and non-retrofit)	III
0503			X			Straight Tube Fluorescent Lamps	III
0504			X			Special Lamps (e.g. professional mercury, high- and low-pressure sodium)	III
0505			X			LED Lamps (incl. retrofit LED lamps)	III
0506			X			Household Luminaires (incl. household incandes-cent fittings and household LED luminaires)	V
0507			X			Professional Luminaires (offices, public space, industry)	V
0601			X		X	Household Tools (e.g. drills, saws, high-pressure cleaners, lawnmowers)	V
0602			X		X	Professional Tools (e.g. for welding, soldering, milling)	IVa
0701			X	X		Toys (e.g. car racing sets, electric trains, music toys, biking computers, drones)	V
0702			X	X		Game Consoles	VI
0703			X		X	Leisure equipment (e.g. sports equipment, electric bikes, jukeboxes)	IVa
0801			X			Household Medical equipment (e.g. thermometers, blood pressure meters)	V
0802			X			Professional Medical equipment (e.g. hospital, dentist, diagnostics)	IVa
0901			X			Household Monitoring & Control equipment (alarm, heat, smoke, excl. screens)	V
0902			X			Professional Monitoring & Control equipment (e.g. laboratory, control panels)	IVa
1001			X			Non-cooled Dispensers (e.g. for vending, hot drinks, tickets, money)	IVa
1002			X			Cooled Dispensers (e.g. for vending, cold drinks)	I

7.2 Combined Projections for EEE POM, E-waste and Stock in Tonnes and Pieces Per Capita
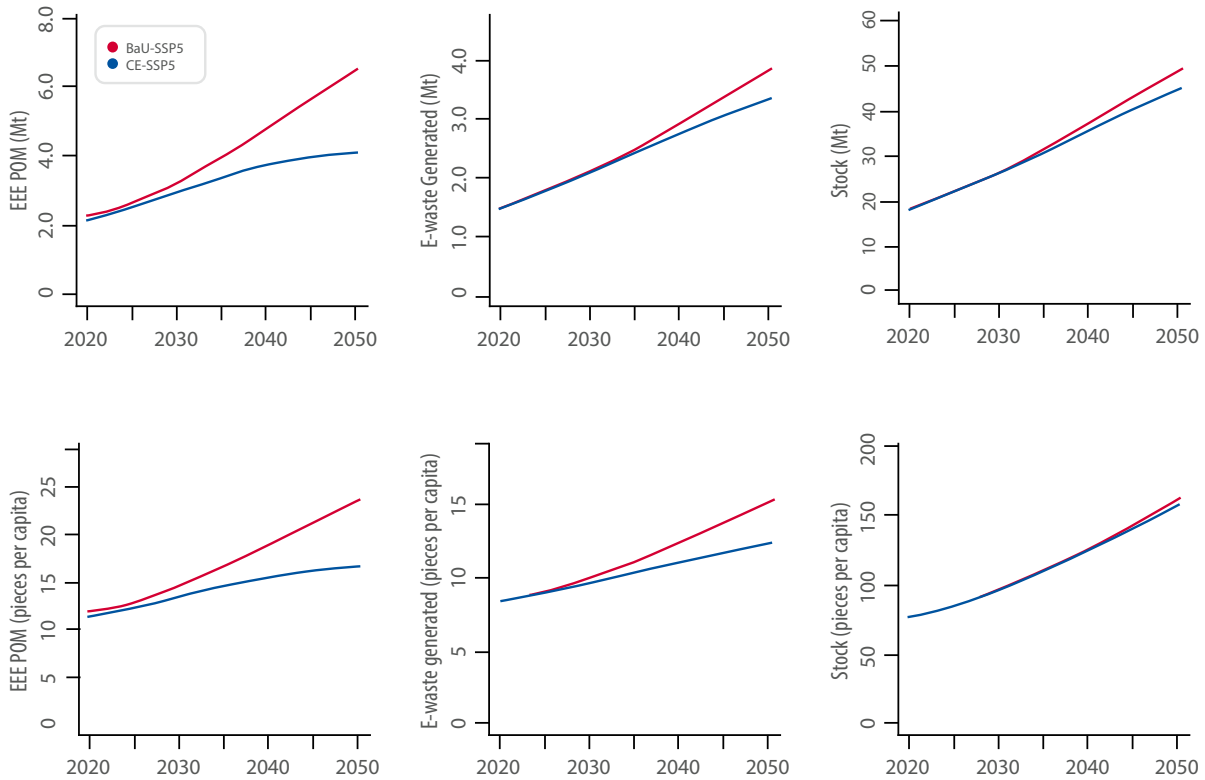
The projections for POM, e-waste generated, and stock under the full set of the SSP scenarios for West Asia are shown in Figure 9. These are based solely on the underlying projected socioeconomic trends as represented by the GDP PPP and population scenarios in each West Asian country. The SSP projections have been downloaded from the SSP database and adjusted to historic country-level GDP PPP and population estimates by the World Bank. These socioeconomic pathways were subsequently used to drive the default POM extrapolation algorithm in the Waste Over Time Model (Van Straalen et al. 2016). The algorithm is based on correlations between historic GDP PPP per capita and POM per capita, along with a number of additional corrections in the cases where the correlations are below an empirically chosen 30% threshold. The algorithm effectively represents a well-established consumer behaviour that has been observed in the wealthier countries over several decades, where greater levels of income have resulted in higher levels of consumption for a wide range of electronic goods. The WOT algorithm also captures certain key technological trends in the electronics sector itself, with new product groups such as IT showing persistent growth followed by, in some cases, market saturation, and with other product groups such as CRT TVs and monitors showing a decline and eventual obsolescence.
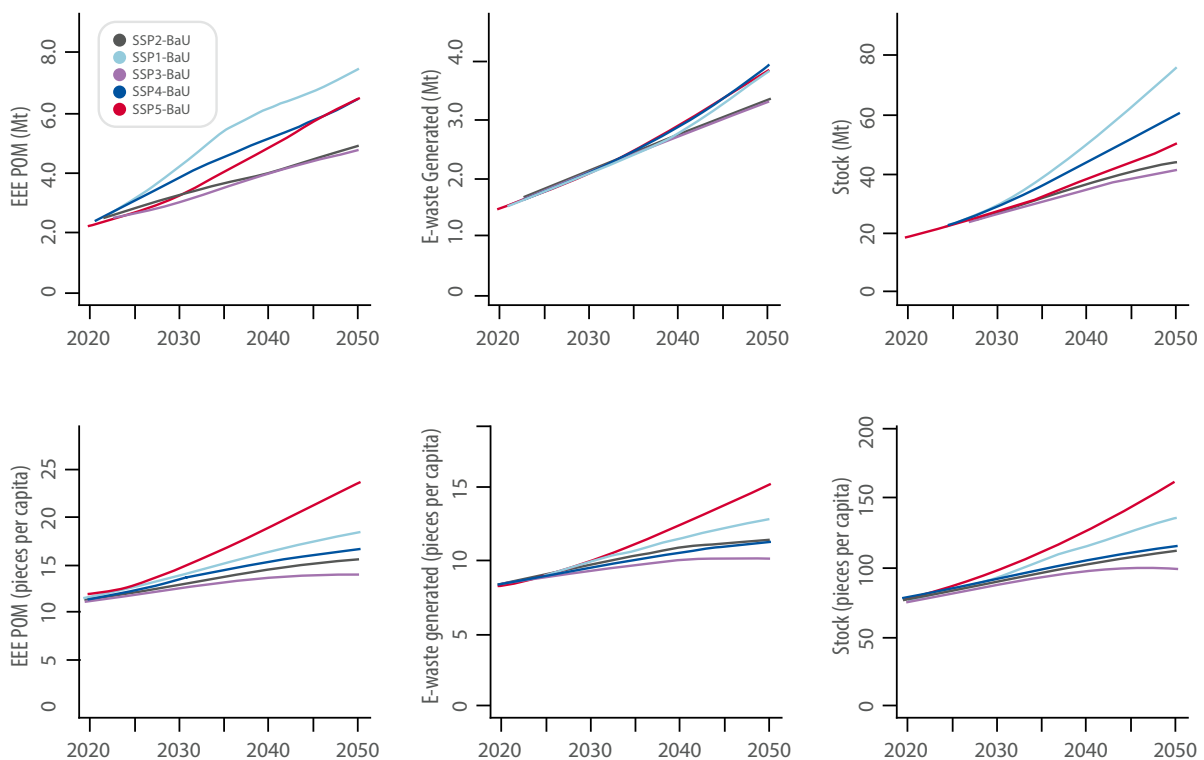
FIGURE 9: Projections to 2050 for POM (left column), e-waste generated (middle column), and stock (right column), both in tonnes (top row) and in pieces per capita (bottom row), for the West Asia region, under five contrasting socioeconomic pathways (SSPs). The results assume present-day consumer behaviour (BaU) for the EEE sector. SSP1 has the highest growth in POM measured in t compared to other SSPs due to a high underlying growth rate in solar photovoltaic installations.

For the sake of comparison, the spread between e-waste generated projections under the BaU and CE pathways, assuming the underlying socioeconomic conditions are in line with SSP5, are plotted in Figure 10.

FIGURE 10: Projections to 2050 for POM (left column), e-waste generated (middle column), and stock (right column), both in tonnes (top row) and in pieces per capita (bottom row), for the West Asia region, assuming either Business as Usual (BaU) or Circular Economy (CE) consumer behaviour and technology pathways for the EEE sector. Underlying socioeconomic pathway: SSP5 (highest levels of economic growth and consumption).

Figure 11 shows stock in tonnes and pieces per capita in 2020, in 2050 under the BaU pathway for the EEE sector, and in 2050 under the CE transition pathway for the EEE sector, plotted separately for high-income and middle- and low-income countries, and for three contrasting SSP scenarios. In all scenarios, the stock continues to grow and is projected to exceed present-day values, even under SSP1 with the CE behaviour and technology change for the EEE sector. This shows that e-waste management will likely remain a challenge well into the second half of the 21st century, even though the pathways with lower growth and better circularity are likely to reduce the recycling burden.
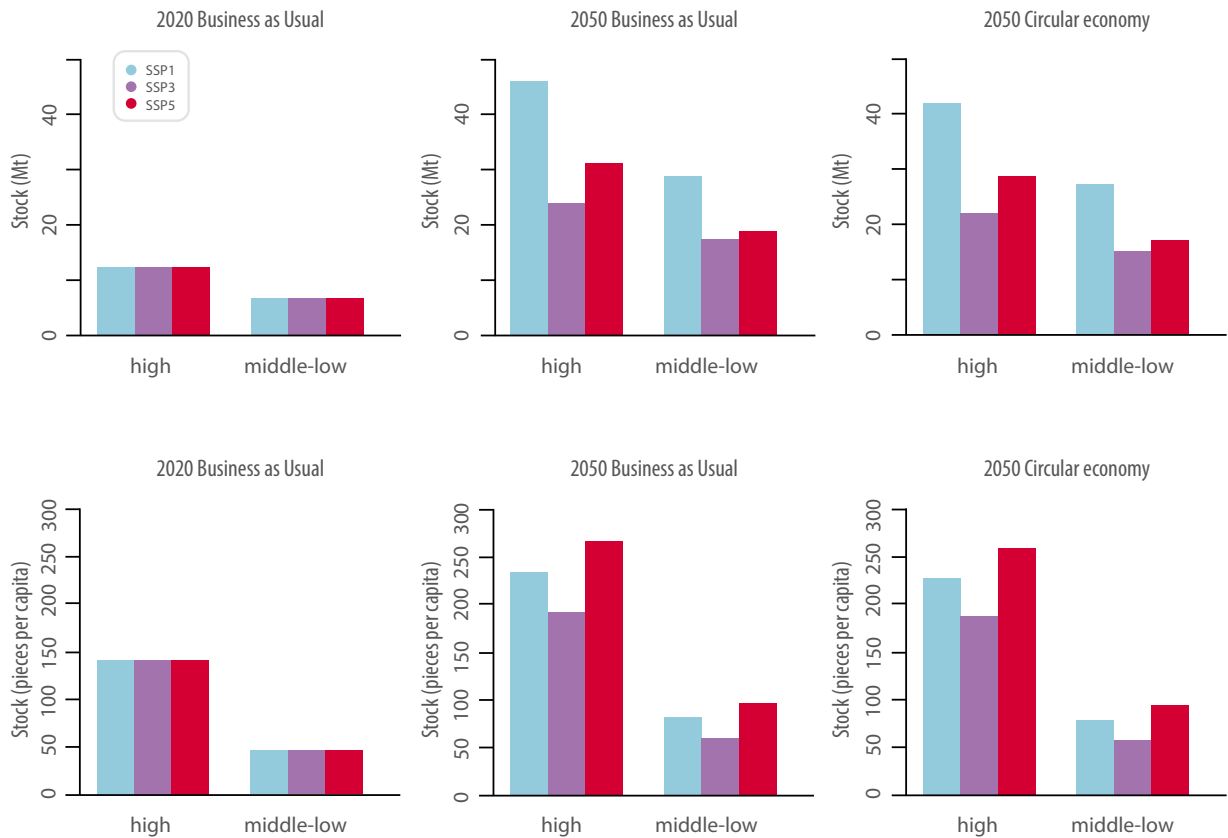
FIGURE 11: Estimated EEE stock in tonnes (Stock_t, top row) and pieces per capita (Stock_ppi, bottom row) in West Asia in 2020 and 2050. The results are given for 2020 (left column), for 2050 under the assumption that current Business as Usual (BaU) consumer behaviour for the EEE sector persists (middle column), and for 2050 under Circular Economy (CE) consumer behaviour and technology changes for the EEE sector (right column). Groups of bars: high-income vs middle- and low-income countries in West Asia. Individual bars: contrasting underlying socioeconomic (SSP) scenarios. SSP1 has the highest growth in POM measured in t compared to other SSPs due to a high underlying growth rate in solar photovoltaic installations.

# 7.3 SSP Scenarios Characterised According to GDP PPP and Population Projections

The SSP projections out to 2050 for the West Asia region shown in Figure 12 are based on the country-level GDP PPP and population pathways from the SSP Database (see References for further details). SSP5, SSP1, and SSP3 provide three contrasting pathways for GDP PPP per capita across all income groups. In the middle- and low-income countries, projected population levels are shown to be on the lower end of the scale for both SSP1 and SSP5 and on the higher end for SSP3. This pattern translates into the population projections for the West Asia region as a whole, since the high-income countries in the region have considerably less variation in the projected populations under different SSPs.
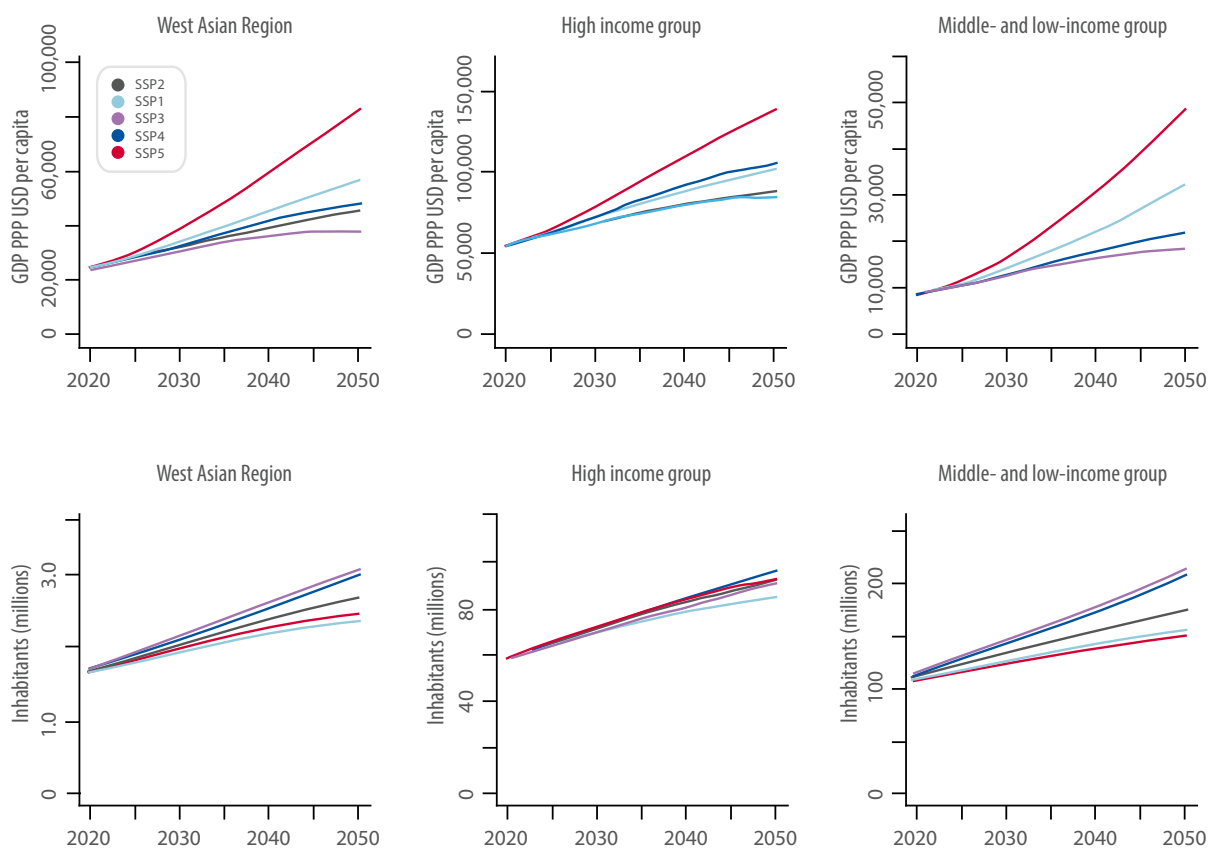
FIGURE 12: SSP projections for GDP PPP per capita (top row) and population (bottom row) in West Asia, plotted for all income groups (left column), the high-income group (centre column), and middle- and low-income groups (right column).

7.4 Adjusted SSP Projections for Solar Photovoltaic Installations in West Asian Countries

We base country-level projections to 2050 for solar photovoltaic installations in West Asia on the relevant SSP scenarios for the region R5.2MAF 'Middle East and Africa'. Specifically, we use the subset of contrasting SSP scenario realisations illustrated in Figure 13. The chosen scenarios are characterised by plausible combinations of the SSP narratives and the resulting global anthropogenic radiative forcing outcomes.
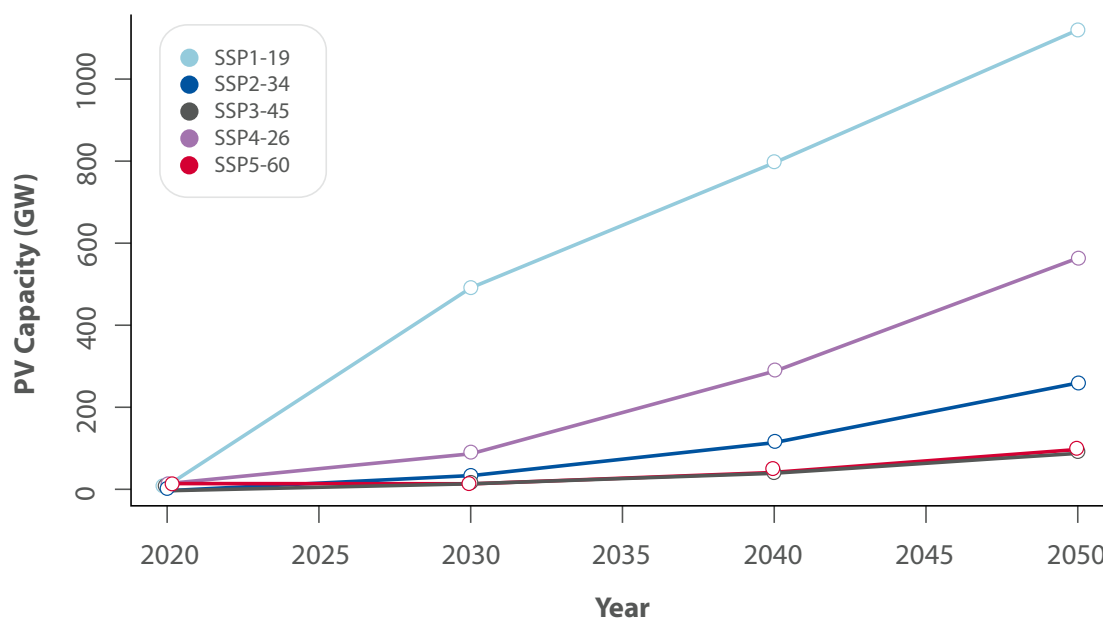
FIGURE 13: Contrasting SSP solar photovoltaic capacity projections for the 'Middle East and Africa' region (R5.2MAF) between 2020 and 2050, with the suffixes in the scenario names indicating the projected levels of global anthropogenic radiative forcing (RF) in 2100. The values are based on 3 out of 5 energy-focused integrated assessment models (IAMs) in the SSP database for which the required subset of SSP scenarios is available.

Table 6 lists the projected 2040 solar photovoltaic capacities in the R5.2MAF region under the chosen SSP scenarios and puts them in the context of global climate mitigation efforts (see the 'Interpretation' column). The year 2040 is chosen here as a reference in order to draw a comparison with the other set of global solar photovoltaic projections currently available, provided by the International Energy Agency (below).

TABLE 6: Contrasting SSP solar photovoltaic capacity projections for the 'Middle East and Africa' region (R5.2MAF) out to 2040, with the suffixes in the scenario names indicating the projected levels of global anthropogenic radiative forcing (RF) in 2100. The values are based on 3 out of 5 energy-focused integrated assessment models (IAMs) in the SSP database for which the required subset of SSP scenarios is available.
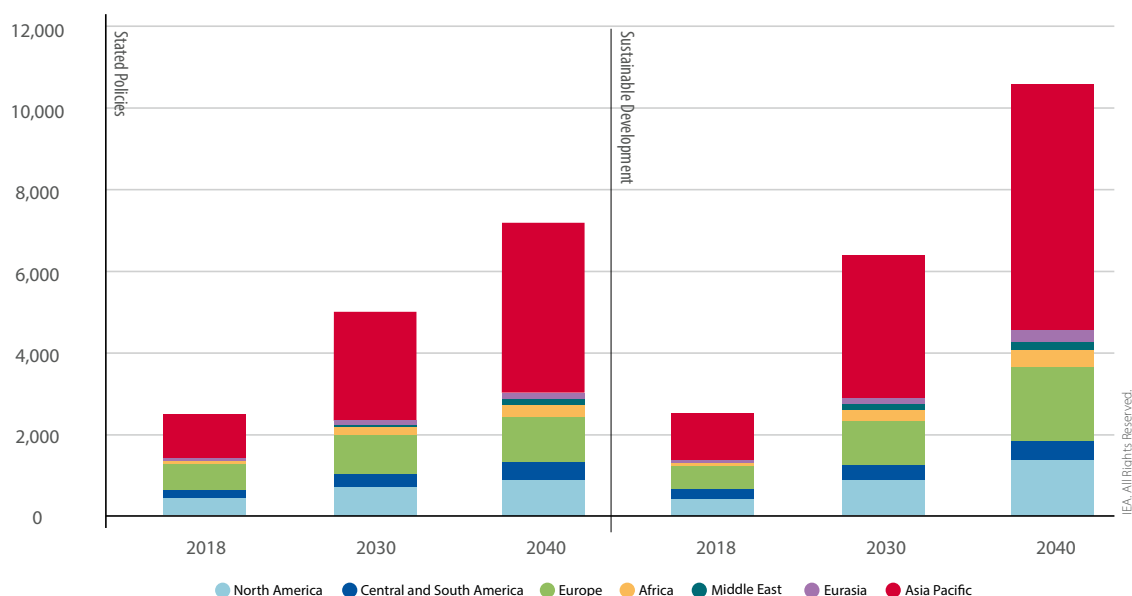
REGION	R5.2MAF	
Variable	Capacity|Electricity|Solar|PV	
Year	2040	

SCENARIO	VALUE & UNITS	INTERPRETATION
SSP1-19	802 GW	Lowest mitigation challenges
SSP2-34	117 GW	Medium mitigation challenges
SSP3-45	42 GW	High mitigation challenges
SSP4-26	291 GW	Low mitigation challenges
SSP5-60	46 GW	Highest mitigation challenges

We note that the SSP5-60 scenario has the highest mitigation challenges (and the greatest reliance on fossil fuels for energy), but its projected installed photovoltaic capacity for 2040 (46 GW) is marginally higher than for the pathway with the second-highest mitigation challenges, SSP3-45 (42 GW). This is because SSP5 is characterised by a bigger economy, which leads to more fossil fuel and more renewable installations than in SSP3, even though the focus in SSP5 remains on fossil fuels.

To split West Asia's solar photovoltaic projections from the combined SSP scenarios for 'Middle East and Africa', we use the IEA 'Sustainable Development' scenario, which gives 411 GW of solar photovoltaic panels for the Middle East and 574 GW for Africa in 2040 (Figure 14). We assume that the resulting split of approximately 42% for West Asia within the R5.2MAF SSP region remains constant between 2020 and 2050 in the adopted SSP scenarios.

FIGURE 14: IEA projections for solar photovoltaic capacities in major world regions in 2040.

Source: https://www.iea.org/data-and-statistics/charts/renewable-electricity-capacity-by-region-and-scenario-2018-2040.

The projected solar photovoltaic capacities in West Asia under the chosen SSP scenarios are characterised by the average exponential and linear growth rates (1/yr) between 2020 and 2050, summarised in Table 7. The exponential fitting works better for SSP2-SSP5, while the linear model better suits SSP1-19. However, the initial annual rate of the photovoltaic capacity installation in the SSPs in year 2020, which is essentially equal to POM, shows an unrealistic jump between SSP1 and the other SSPs. Moreover, neither of the SSPs matches well with the recent historic data or with the IEA projections for West Asia. For example, the 2040 IEA solar photovoltaic projections for the combined 'Middle East and Africa' region under the 'Sustainable Development' scenario, which sees the highest photovoltaic growth by 2040 (985 GW), are roughly 23% higher than the 2040 SSP1-19 projections for the same region (802 GW), thus being the highest among all SSPs. Therefore, we need to scale all SSPs accordingly in line with the highest IAE projections. Furthermore, the IEA scenario for West Asia is closer to exponential growth, with an average rate of 0.22 1/yr between 2019 and 2040, which does not fit with the SSP1-19 trajectory. Additionally, the historic data for recent photovoltaic installations in the West Asia region (IRENA dataset) shows a comparatively fast exponential growth with an average rate of 0.55 1/yr, but while this rate is rather high, it should gradually evolve under the contrasting SSPs. The original SSP dataset, on the other hand, shows a large jump in the initial photovoltaic installation rate between SSP1 and SSP2-SSP5. All these considerations call for further adjustments to be made to the SSP photovoltaic scenarios in order to make them suitable for POM and e-waste projections.

TABLE 7: Exponential and linear growth rates of solar photovoltaic capacities in West Asia, inferred from the SSP scenarios. SSP1-19 does not have an exponential rate since it does not fit the exponential growth model.

SCENARIO	EXPONENTIAL RATE (1/YR)	LINEAR RATE (GW/YR)
SSP1-19	NA	15.22
SSP2-34	0.129	3.51
SSP3-45	0.095	1.19
SSP4-26	0.124	7.76
SSP5-60	0.112	1.33

To avoid jumps in the derivative of the cumulative photovoltaic capacity while keeping the projections consistent both with historic photovoltaic data and SSP scenarios, we use a model with an exponentially decreasing exponential rate of the capacity change. We employ the double-exponential model to derive normalised cumulative capacity in WA under a given scenario and partition it for each country according to its recent historic photovoltaic capacity data (in the near-term) and projected relative GDP share (in the long-term).

The starting rate for the model is inferred from the historic IRENA data for WA, resulting in 0.55/yr. We assume that this rate will decrease exponentially with time, converging onto the projected GDP growth rate for WA under a given scenario. The resulting cumulative growth for the SSP1-19 scenario will then be adjusted to the IEA projections in 2040 for the Sustainable Development scenario, with the values for other SSPs scaled proportionately according to the linear rates for WA derived above (from 1.2 to 15.2 GW/yr). All scaling is performed through adjusting the exponential decay parameter β of the main exponential rate to ensure that there are no jumps in the time derivative of the cumulative capacity (proportional to POM).

The required country-level breakdown of the WA projections are achieved by using a combination of two factors: (i) initial conditions for the exponential model in line with the IRENA data for 2019, and (ii) gradual shift from the effect of the initial conditions to a GDP-driven share of each country relative to the WA GDP. The latter ensures that countries that have made a slow start but which have sufficient wealth are going to catch up with the installation in the long run. We are going to use a linear multiplier function between 2019 and 2050 to implement the shift in the per-country scaling of the exponential formula.

The formula for the exponentially decreasing rate of installation of new solar photovoltaic capacity for West Asia as a whole is:

$$\alpha_k(t) = r_k(t) + (\alpha_0 - r_{(0,k)}) \cdot \exp(-\beta_k \cdot (t - 2019))$$

Here, k is scenario, $r_k = (dGDP_k/dt)/GDP_k$ is the relevant GDP growth rate in West Asia, $r_{(0,k)} = r_k (2019)$, α_0 is the recent historic growth rate in West Asia inferred from the IRENA data, β_k is the rate of decay of the installation rate under scenario k (determined from an optimisation algorithm to match the IEA 2040 projections and inter-SSP scenario spread), and t is year (from 2019 to 2050).

The equation for the cumulative installed solar photovoltaic capacity $C_k(t)$ in West Asia under scenario k is:

$$\frac{dC_k}{dt} = \alpha_k(t) \cdot C_k(t)$$

The equation is integrated numerically, with an optimisation algorithm employed to fit with IEA-adjusted linear SSP projections in 2040 for each SSP by choosing an appropriate value of β. The subsequent per-country partition is achieved by combining the recent historic data from IRENA (near-term) and the relative share of each country's GDP in West Asia (long-term). Countries with a higher GDP share of the West Asia total are gradually being allocated a proportionally higher share of the photovoltaic installations as time runs from the base year (2019) to 2050. The resulting adjusted SSP projections for solar photovoltaic capacity in the West Asia region as a whole, represented as annual installed capacities dC_k/dt for a given SSP scenario k, are plotted in Figure 15. The corresponding cumulative installations $C_k(t)$ are shown in Figure 16.
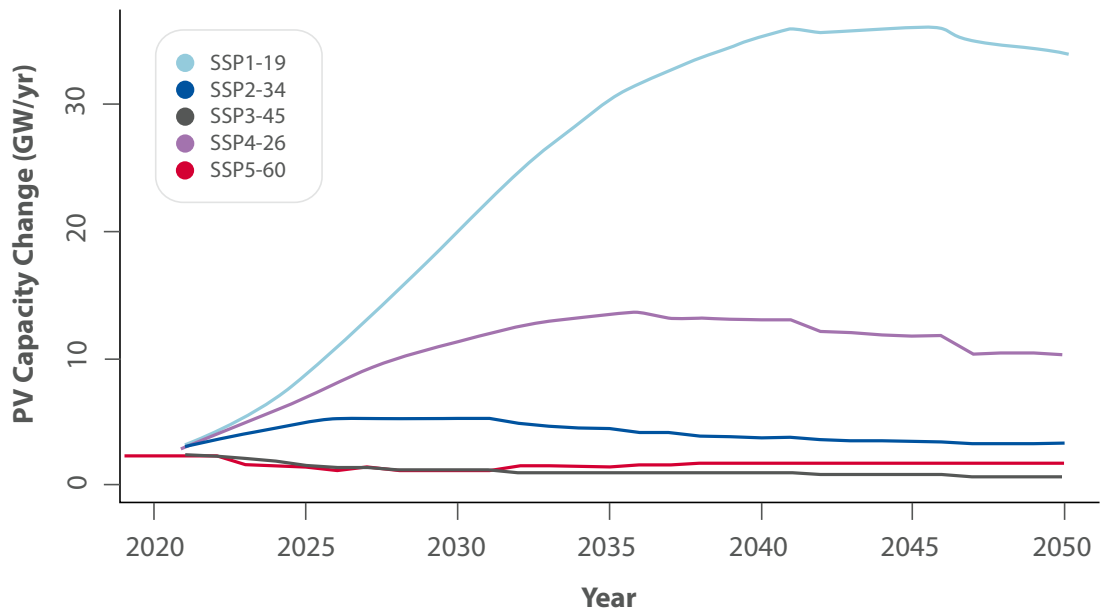
FIGURE 15: Adjusted SSP scenarios for solar photovoltaic capacity in West Asia between 2020 and 2050 (annual rates, GW/yr).
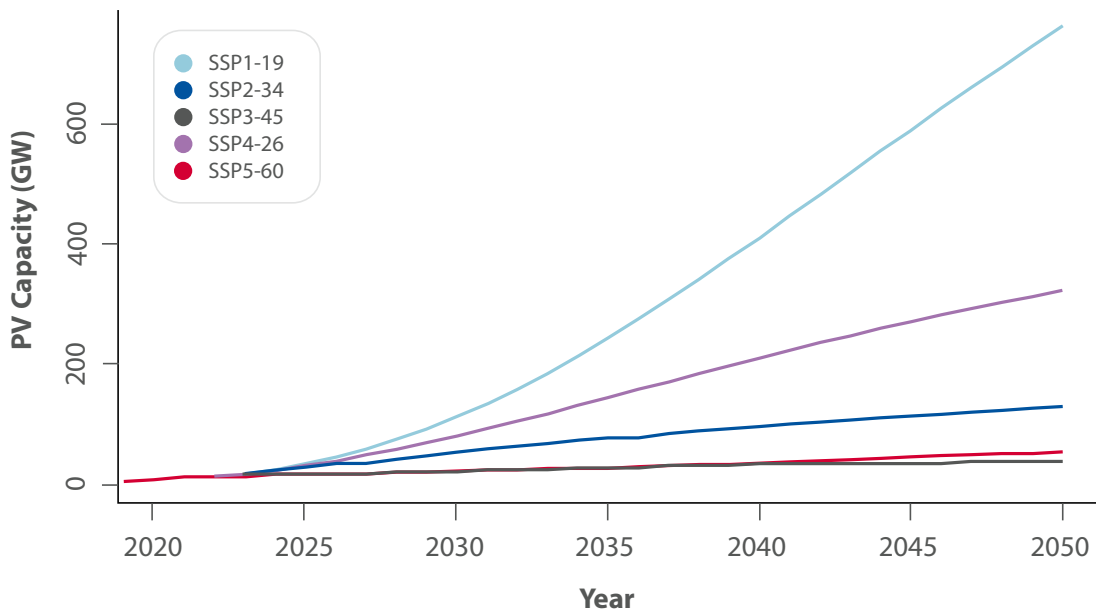

FIGURE 16: Adjusted SSP scenarios for solar photovoltaic capacity in West Asia between 2020 and 2050 (cumulative installed capacity, GW).

7.5 Narratives Underpinning SSP Scenarios

The descriptions below are quoted from (Riahi et al. 2017). The components most relevant to the EEE sector, including the CE transition in consumer behaviour, technology, and e-waste collection, are underlined.

SSP1 Sustainability –

Taking the Green Road (Low Challenges to Mitigation and Adaptation)
- The world shifts gradually, but pervasively, toward a more sustainable path, emphasizing more inclusive development that respects perceived environmental boundaries.
- Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and the emphasis on economic growth shifts toward a broader emphasis on human well-being.
- Driven by an increasing commitment to achieving development goals, inequality is reduced both across and within countries.
- Consumption is oriented toward low material growth and lower resource and energy intensity.

SSP2 Middle of the Road

(Medium Challenges to Mitigation and Adaptation)
- The world follows a path in which social, economic, and technological trends do not shift markedly from historical patterns.
- Development and income growth proceeds unevenly, with some countries making relatively notable progress while others fall short of expectations.
- Global and national institutions work toward but make slow progress in achieving sustainable development goals.
- Environmental systems experience degradation, though there are some improvements and overall, the intensity of resource and energy use declines.
- Global population growth is moderate and levels off in the second half of the 21st century.
- Income inequality persists or improves only slowly, and challenges to reducing vulnerability to societal and environmental changes remain.

SSP3 Regional Rivalry –

A Rocky Road (Significant Challenges to Mitigation and Adaptation)
- A resurgent nationalism, concerns about competitiveness and security, and regional conflicts push countries to increasingly focus on domestic or, at most, regional issues.
- Policies shift over time to become increasingly oriented toward national and regional security issues.
- Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development.
- Investments in education and technological development decline. Economic development is slow, consumption is material-intensive, and inequalities persist or worsen over time.
- Population growth is low in industrialised and high in developing countries.
- A low international priority for addressing environmental concerns leads to strong environmental degradation in some regions.

SSP4 Inequality –

A Road Divided (Low Challenges to Mitigation, High Challenges to Adaptation)

• Highly unequal investments in human capital, combined with increasing disparities in economic opportunity
  and political power, lead to increasing inequalities and stratification both across and within countries.

• Over time, a gap widens between an internationally-connected society that contributes to
  knowledge- and capital-intensive sectors of the global economy and a fragmented collection
  of lower-income, poorly educated societies that work in a labour intensive, low-tech economy.

• Social cohesion degrades, and conflict and unrest become increasingly common.

• Technology development is high in the high-tech economy and sectors.

• The globally connected energy sector diversifies, with investments in both carbon-intensive fuels
  like coal and unconventional oil, but also in low-carbon energy sources. Environmental policies focus
  on local issues around middle- and high-income areas.

SSP5 Fossil-fuelled Development –

Taking the Highway (High Challenges to Mitigation, Low Challenges to Adaptation)

• This world places increasing faith in competitive markets, innovation, and participatory societies to produce
  rapid technological progress and development of human capital as the path to sustainable development.

• Global markets are increasingly integrated. There are also strong investments in health, education,
  and institutions in order to enhance human and social capital.

• Likewise, the push for economic and social development is coupled with the exploitation of abundant
  fossil fuel resources and the adoption of resource- and energy-intensive lifestyles around the world.

• All of these factors lead to rapid growth of the global economy, while global population peaks and
  declines in the 21st century.

• Local environmental problems such as air pollution are successfully managed.

• There is faith in the ability to effectively manage social and ecological systems,
  including by geo-engineering, if necessary.

## 7.6 Combined Projections for EEE POM, E-waste, and Stock Under Selected SSP and CE Scenarios

In the presentation of the key results in this report, each of the underlying socioeconomic (SSP) pathways is complemented with either the BaU or the CE pathways specifically for the EEE sector, with the latter including the 100% e-waste collection target. While by its design, the SSP1 pathway is naturally aligned with the CE consumer behaviour, technology assumptions, and high e-waste collection rates, and while both SSP3 and SSP5 fit better with the present-day 'BaU' e-waste patterns with low circularity and low collection rates, the built-in policy flexibility in the SSP definitions (Riahi et al. 2017; Kriegler et al. 2014) implies that nearly all scenario combinations are possible. The outcomes for the EEE sector under a given SSP scenario could vary as much as the associated economy-wide greenhouse gas emissions (Riahi et al. 2017), even though combining a less sustainable SSP scenario for GDP and population with a more circular pathway specifically for the EEE sector, for example, would require strong and targeted policy interventions and is generally less likely to occur. Likewise, a more sustainable SSP scenario world could still have a less circular EEE sector, which is also less likely to occur and could be caused by a lack of targeted e-waste policies amid focusing the sustainability efforts elsewhere (e.g. on the energy and land use sectors).

7.7 Country Data

TABLE 8: **EEE POM and e-waste generated for each country in West Asia.**
The mean results are provided in 2020, in 2050 under the BaU scenario, and in 2050 under the CE scenario.

	POM KTON				WEEE KTON		
	2020	**2050 BAU**	**2050 CE**		**2020**	**2050 BAU**	**2050 CE**
ARE	306	541	332	**ARE**	160	373	326
BHR	37	110	77	**BHR**	24	65	56
IRQ	472	1470	1050	**IRQ**	278	855	748
JOR	131	246	173	**JOR**	52	153	132
KWT	96	318	211	**KWT**	64	178	153
LBN	80	139	97	**LBN**	56	103	90
OMN	122	292	187	**OMN**	70	185	160
PSE	35	75	54	**PSE**	23	50	43
QAT	75	184	121	**QAT**	40	122	104
SAU	805	2260	1500	**SAU**	572	1350	1164
SYR	82	267	206	**SYR**	81	141	120
YEM	50	119	86	**YEM**	41	77	65
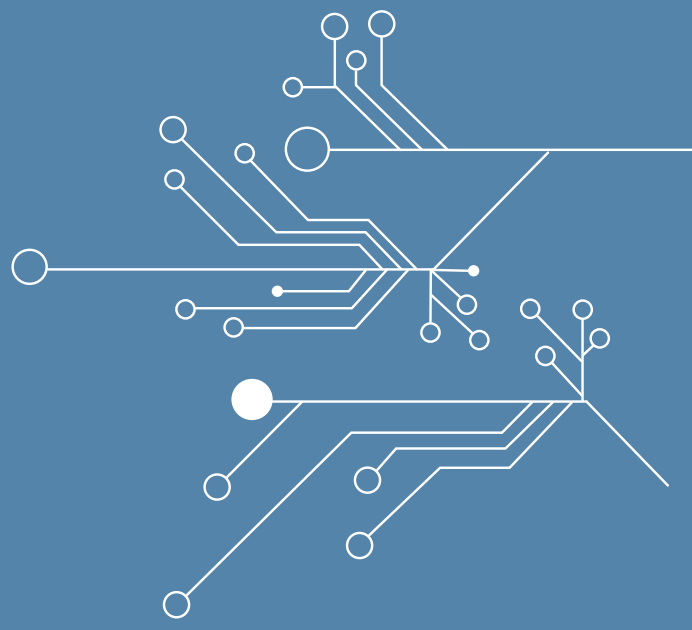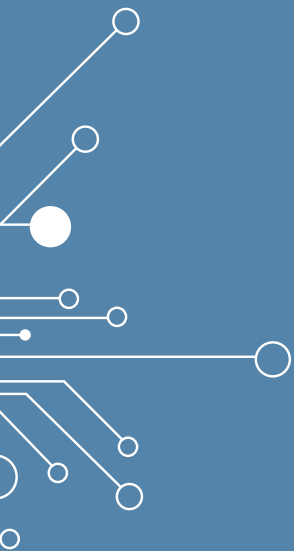
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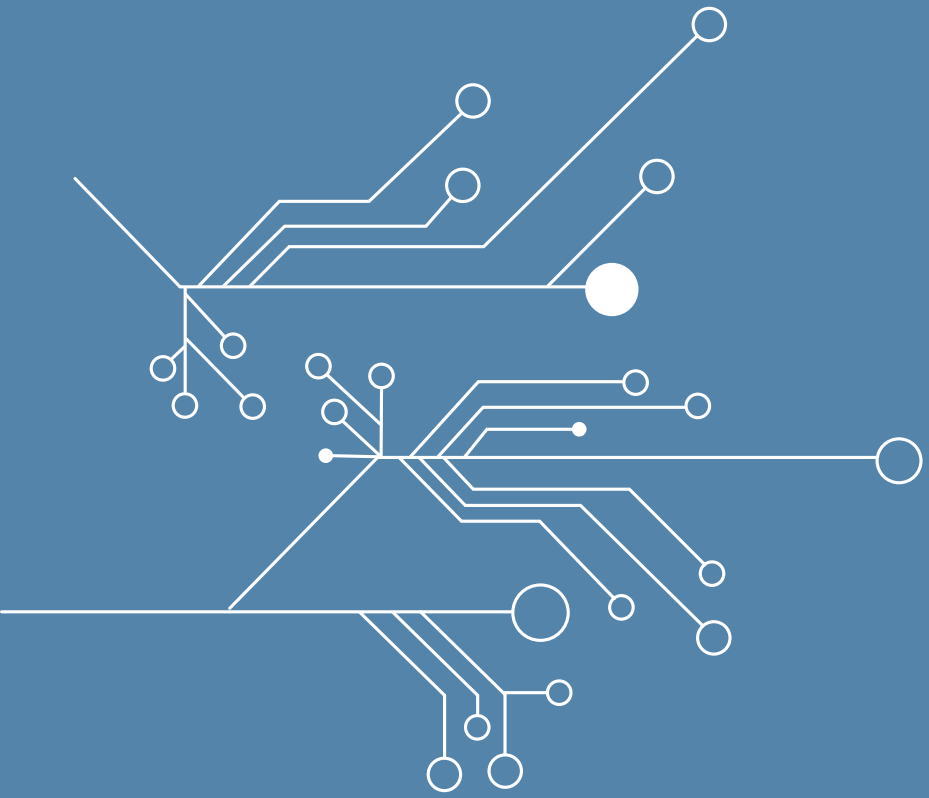
References

Baldé, C.P., Kuehr, R., Blumenthal, K., Fondeur Gill, S., Kern, M., Micheli, P., Magpantay, E. and Huisman, J. (2015).
E-waste Statistics: Guidelines on Classifications, Reporting and Indicators.
United Nations University, IAS-SCYCLE, Bonn, Germany.

European Commission,
Directive 2008/98/EC of the European Parliament and
of the Council of 19 November 2008 on waste.
URL: http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:312:0003:0030:EN:PDF.

Forti, V., Baldé, C.P. and Kuehr, R. (2018).
E-waste Statistics: Guidelines on Classifications,
Reporting and Indicators, second edition.
United Nations University ViE – SCYCLE, Bonn, Germany. 2018.
URL: http://collections.unu.edu/view/UNU:6477.

Forti, V., Baldé, C.P., et al. (2020).
The Global E-waste Monitor 2020 –
Quantities, flows, and the circular economy potential.
UNU/UNITAR & ITU.

Huisman, J., Leroy, P., Tertre, F., Ljunggren Söderman, M., Chancerel, P. Cassard,
D. Løvik, A.N., Wäger, P., Kushnir, D., Rotter, V.S., Mählitz, P., Herreras, L., Emmerich, J.,
Hallberg, A., Habib, H., Wagner, M., Downes, S.
Prospecting Secondary Raw Materials in the Urban Mine and
mining wastes (ProSUM) - Final Report,
ISBN: 978-92-808-9060-0 (print), 978-92-808-9061-7 (electronic),
December 21, 2017, Brussels, Belgium.

Iattoni, G., Vermeersch, E., Baldé, C.P., Nnorom, I.C., & Kuehr, R. (2021).
Regional E-waste Monitor for the Arab States, 2021.
Bonn, Germany and Geneva, Switzerland.

Kriegler, E., Edmonds, J., Hallegatte, S. et al. (2014).
A new scenario framework for climate change research:
the concept of shared climate policy assumptions.
Climatic Change 122, 401–414.

Lydall, M. Nyanjowa, W. and James, Y. 2017.
Mapping South Africa's Waste Electrical and Electronic Equipment (WEEE)
Dismantling, Pre-Processing and Processing Technology Landscape,
Mintek External Report # 7574.

McCann, D., & Wittmann, A. (2015).
E-waste Prevention, Take-back System Design and Policy Approaches,
StEP Green Paper.

McMahon, K., Ryan-Fogarty, Y. and Fitzpatrick, C. (2021).
Estimating job creation potential of compliant WEEE pre-treatment in Ireland
Resources, Conservation and Recycling, Volume 166, March 2021, 105230.

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., &
Tavoni, M. (2017).
The shared socioeconomic pathways and their energy, land use,
and greenhouse gas emissions implications: an overview.
Global Environmental Change, 42, 153-168.

The Reuse and Recycling EU Social Enterprises network (2015)
Briefing on job creation potential in the re-use sector, RREUSE.
URL: https://rreuse.org/wp-content/uploads/Final-briefing-on-reuse-jobs-website-2.pdf.

Strategic Approach to International Chemicals Management (2018).
Second meeting of the intersessional process considering the
Strategic Approach and and the sound management of chemicals and
waste beyond 2020, March 2018,
item 4 of the agenda
"Gender and the sound management of chemicals and waste"
URL: http://www.saicm.org/Portals/12/documents/meetings/IP2/IP_2_6_gender_
document.pdf.

Sayers, M., et al. (2020).
Electrical Waste – Challenges and Opportunities:
An investigation into Waste Electrical and Electronic Equipment (WEEE)
flows in the UK.
Anthesis | Lancaster University | Repic | Valpack.

Shaikh, S. (2021).
Chapter 4 in PhD-thesis - A critical analysis of e-waste management and
recycling in Pakistan: a life cycle assessment,
March 2021, Victoria University, Melbourne, Australia.

SSP Database (Shared Socioeconomic Pathways) –
Version 2.0. IIASA, 2018.
URL: https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=10.

Umair, S., Björklund, A. & Petersen, EE (2015).
'Social impact assessment of informal recycling of electronic ICT waste
in Pakistan using UNEP SETAC guidelines',
Resources, Conservation & Recycling, vol. 95, pp. 46-57.

United Nations Economic Commission for Europe (2021).
Task Force on Waste Statistics – Conference of European Statisticians.
UNECE, Geneva, 2021 under approval (United Nations Economic Commission
for Europe, UNECE).

United Nations Environment Programme (2019).
Global Environment Outlook – GEO-6: Healthy Planet, Healthy People. Nairobi.
DOI 10.1017/9781108627146.

United Nations Environment Programme and Global Resource
Information Database (2009).
Gender and waste nexus: experiences from Bhutan, Mongolia and Nepal.
URL: https://wedocs.unep.org/bitstream/handle/20.500.11822/29821/
GaWN.pdf?sequence=1&isAllowed=y.

United Nations Environment Programme and
Solving the E-Waste Problem Initiative (2009).
Recycling – from e-waste to resources.

United Nations,
Department of Economic and Social Affairs, Population Division (2019).
World Population Prospects 2019, Online Edition. Rev. 1.
URL: https://population.un.org/wpp/Download/Standard/Population/

Van Straalen, V.M, Roskam, A.J., & Baldé, C.P. (2016).
Waste over Time [computer software].
The Hague, The Netherlands: Statistics Netherlands (CBS).
URL: http://github.com/Statistics-Netherlands/ewaste

Upstream generation of e-waste and consumer recycling behaviour GDP,
PPP (current international $) – International Comparison Program,
World Bank | World Development Indicators database,
World Bank | Eurostat-OECD PPP Programme.
URL: https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD.

World Development Indicators.
The World Bank Group, 2021.
URL: https://databank.worldbank.org/source/world-development-indicators.

Woroniuk, B. and Schalkwyk, J., 1999,
Note prepared for Sida
URL: http://www.oecd.org/dac/gender-development/1849277.pdf.

WEST ASIA

BAHRAIN, IRAQ, JORDAN, KUWAIT, LEBANON, OMAN, STATE OF PALESTINE, QATAR, SAUDI ARABIA, SYRIAN ARAB REPUBLIC, UNITED ARAB EMIRATES AND YEMEN
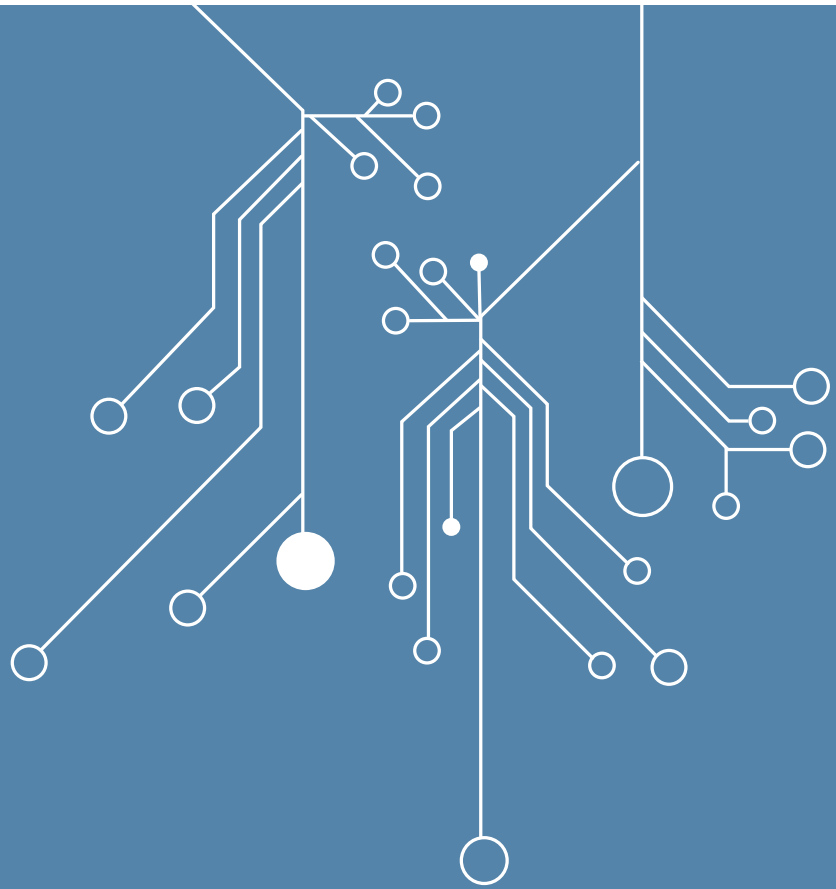
99.9%

OF ELECTRICAL AND ELECTRONIC WASTE EQUIPMENT IS CURRENTLY UNMANAGED OR MISMANAGED

THIS CAN BE CHANGED IF IMMEDIATE ACTION IS TAKEN AND SHIFT TOWARDS A CIRCULAR ECONOMY IS REALIZED.

By 2050, valuable and critical resources can be recovered (130 t of gold, 17 Mt of iron and steel, 1.5 Mt of Copper, 2.6 Mt of Aluminium, 11 kt of Cobalt, 5 kt of rare earth metals), and emissions of 53 Mt of CO_2e and hazardous substances (6 t mercury, 60 t cadmium, 11 kt lead, 19 kt brominated flame retardants), are mitigated.