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Integrating Stocks, Collection and Treatment Pathways in an Urban Material Flow Analysis of Electrical and Electronic Equipment

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Summary:

Waste Electrical and Electronic Equipment (WEEE) is the world's fastest growing waste stream, with 62 million tonnes generated annually. Yet less than a quarter of WEEE is formally collected leading to widespread environmental and socio-economic harm. Evidence on the consumption, disposal and treatment of Electrical and Electronic Equipment (EEE) remains limited hindering adoption of circular economy. Here we use Material Flow Analysis to quantify the annual stocks and flows of EEE in London across the lifecycle, capturing product-source- and pathway-level detail. In 2024, London consumed 255.6k tonnes of new EEE, discarding only 134.5k tonnes, with household stocks increasing 4.4% annually. Less than a quarter of EEE was reused, repaired and remanufactured, and notably, more than half of the WEEE generated was not formally collected or treated. In an ambitious scenario, increasing reuse and remanufacture could reduce EEE placed on the market by 8%, and increasing repair could reduce consumption by 2.8%. Doubling formal collection rates has the potential to increase recycling rates from 33.8 to 48.2k tonnes. The findings identify stocks, end of first use and collection as critical intervention points; and highlight that circular economy strategies must consider product and source heterogeneity in order to strengthen material resilience.

Article:

Introduction

Waste Electrical and Electronic Equipment (WEEE) is the fastest growing waste stream worldwide, with 62 million tonnes having been produced globally in 2022.[1] However, only about 22% of the WEEE produced is formally collected and recycled.[1] This represents a significant environmental burden and loss of economically valuable materials. Leakage of WEEE poses human and environmental health risks, and an estimated 2.01 CO_2 emissions could be avoided for every tonne of WEEE recovered.[2] Furthermore, 91 billion US dollars of critical minerals and precious metals are lost in WEEE annually.[1] Developing a circular economy (CE) strategy for Electrical and Electronic Equipment (EEE) is therefore key to deliver widespread economic, environmental and societal benefits. However, achieving this requires end-to-end, product-specific evidence on consumption patterns, product lifetimes and the pathways through which products accumulate in use, are collected and ultimately undergo treatment. At a city-level, such evidence is essential for identifying existing and potential circular activities, directing investment in collection and recycling infrastructure, and expanding higher-value strategies such as reuse, repair, refurbishment and remanufacturing.

Models to quantify e-waste provide global, regional and national estimates of EEE placed on the market (POM), in stock and waste generated.[3,4] Other studies have examined historical trends in the consumption of critical metals in household EEE[5], domestic and international flows of specific products, such as computers in the US[6], and WEEE management systems in different national or regional contexts e.g. household disposal in Hong Kong[7], Malaysia[8], and the Italian region of Lombardia[9]. However existing studies rarely capture the full stock and flows of use, collection pathways, and final treatment pathways, often providing snapshots of parts of the value chain without including the full relationships. Existing metrics quantify products placed on the market and formally collected (after they are designated as waste), with limited visibility of in-use stocks and second-use pathways. In particular, there lacks evidence

on the extent to which products enter higher value pathways such as reuse, repair and remanufacture. Studies also do not show in detail how these flows vary for different EEE categories (e.g. small domestic appliance, large domestic appliance, IT and telecoms) or source type (e.g. household or commercial sectors). As such, there is limited understanding about which product categories or sources generate the most waste, pollution and emissions, hindering effective policy, infrastructure planning and industry decision-making on CE. This research is key to establishing material level strategies, particularly on critical raw materials.

To address this research problem, the study develops a detailed Material Flow Analysis (MFA) of EEE, covering products used and discarded during 2024 in London, classified according to the 14 UK WEEE categories[10]. The urban scale is particularly important because cities concentrate consumption and in-use stocks, representing an "urban mine" of critical raw materials, and at the same time, they provide a place-based account to examine practical levers for enabling the circular economy.[11]

Following the UNU E-waste Statistical Framework methodology[12], the study follows the flows of EEE placed on the market (POM) in London, through their use-phase as stocks both in households and in the commercial and public sector, considering potential second use through reuse, repair and remanufacturing, collection after disposal, and up to end-of-life treatment, Figure 1. By resolving London's EEE system by product category, source and pathway, the study identifies priority intervention points for retaining products and materials at higher value. It thereby provides an evidence base for urban WEEE policy, CE investment and infrastructure planning in the UK, with potential relevance to other large urban cities.

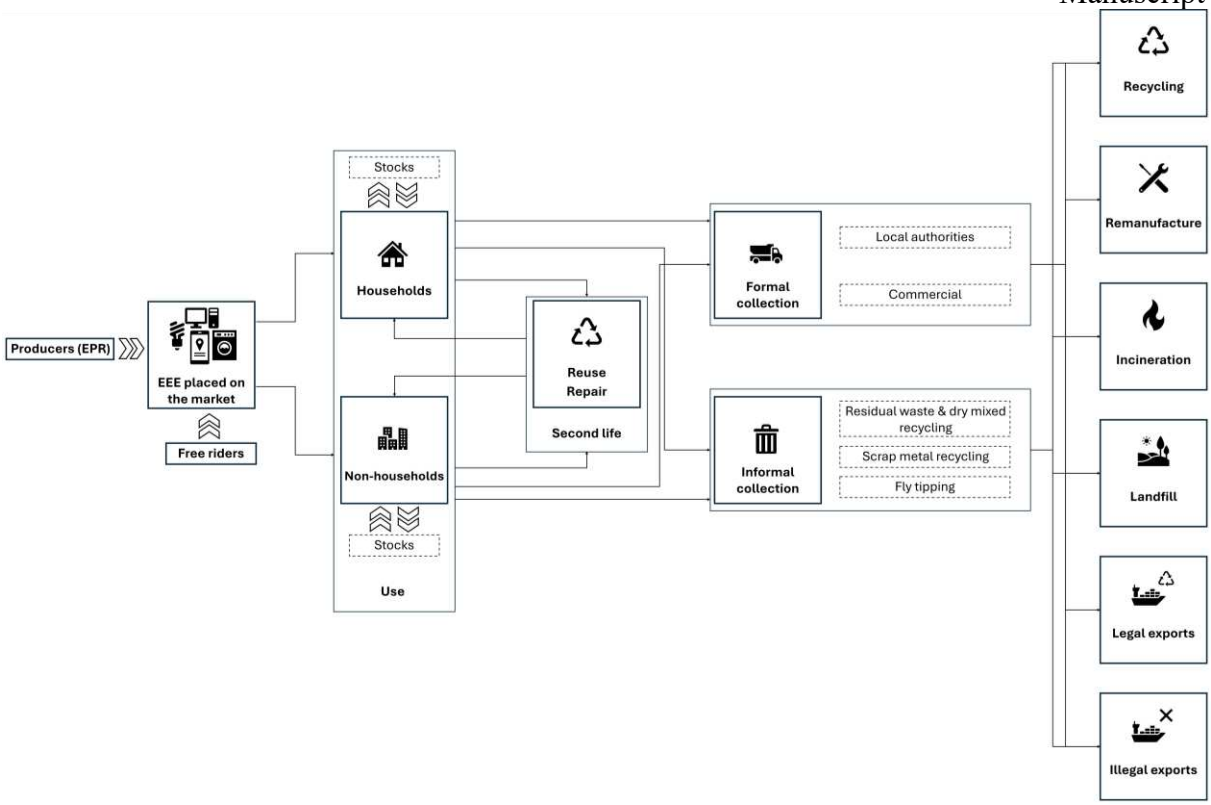

Figure 1 – Schematic representation of the processes and flows considered in the study.

Data was collected from various sources including the UK Environment Agency[13], WasteDataFlow[14], the UK Office for National Statistics[15], the UNU E-waste statistics[12], privately collected data from stakeholders across the value chain. The methodology and data were validated through engagement with experts and stakeholders across the EEE value chain, both by conducting structured individual interviews and in three workshops between 2025-2026 with over 90 industry engagements. For more detailed information on the methodology and data used, please read the Methods section.

Results

The MFA quantified the flows of EEE in London during 2024, from placement on the market, accumulation in in-use stocks to second-use, collection and end of life (see Figure 2). 255.6k tonnes of new EEE was placed on the market in 2023, with households being responsible for 79.1% (202.1k tonnes) of these purchases, corresponding to 22.8 kg per capita[16]. It was also

found that 1.7% of the new EEE purchased was placed on the market in London by unregistered producers or free riders, who do not register and report their products under the WEEE Regulations[17]. Although online marketplaces became subject to WEEE regulations in 2026, free-riding in 2024 was a mainly a result of online marketplaces or direct sales overseas.

During the same year, 140.4k tonnes of EEE reached the end of its first use phase (Figure 2a). Households accounted for 80.8% of these products, equivalent to 12.5 kg per capita, whereas businesses and public institutions were responsible for the remaining 19.2% (Figure 2b). The significant difference between the amount of EEE bought and that disposed of suggests the accumulation of considerable stocks of EEE. Applying the UNU (United Nations University) E-waste Statistical Framework methodology[12], it was estimated that London contained 3,426.6k tonnes of EEE in stock. Household stock amounted to 2,491.5k tonnes, whereas of non-households corresponded to 935.1k tonnes. Households EEE stocks increased 4.4% from 2023 to 2024.

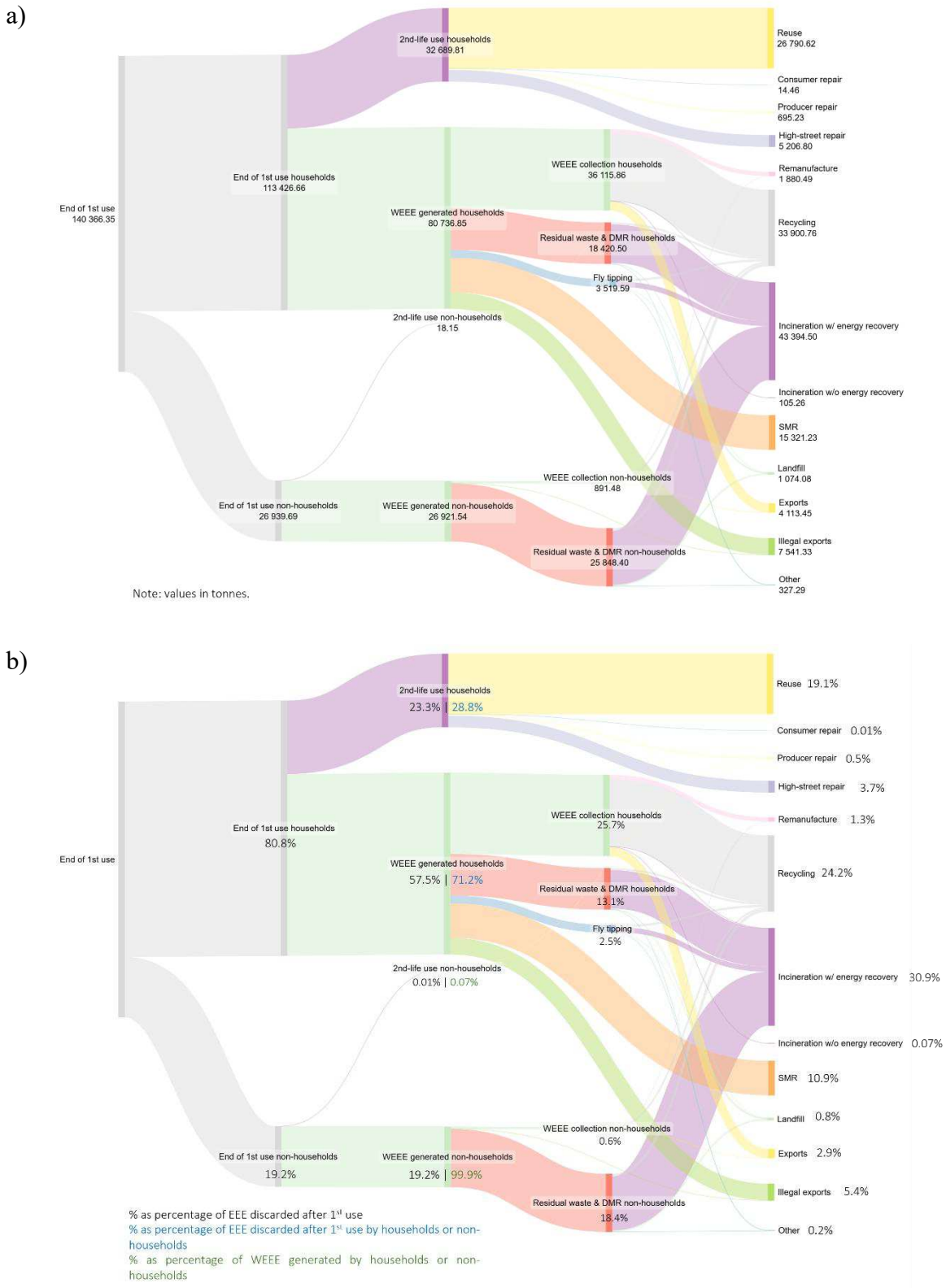

Figure 2 – Sankey diagrams depicting the pathways of WEEE flows in London, in 2024, from the moment they are disposed of after first use (End of 1st use) by households and non-households, up to different end-of-life treatments, in a) tonnes, and as b) percentages of EEE discarded after 1st use, and of WEEE generated (i.e., WEEE not directed to second-life use).

The composition of these stocks differed by product categories. At the product level, Large Household Appliances (40.1%), Cooling Appliances (15.1%) and Small Household Appliances (11.9%) represented the largest share of household stocks. For non-households, IT and Telecommunication Equipment (27.5%) constituted the largest category followed by Lighting Equipment (17.0%) and Cooling Appliances (11.2%).

Of the 140.4kt of EEE reaching end of first use, 32.7k tonnes of EEE were directed to second-life use for reuse or repair. This represented 23.3% of the total EEE discarded after first use, with households contributing the majority of these flows (Figure 2). The remaining 107.7k tonnes was classified as WEEE. Only 37.0k tonnes is formally collected, meaning that 65.6% of WEEE generated is disposed of via informal or improper collection routes, such as in residual waste and dry mixed recycling (DMR) bins, fly tipped (households only), diverted for informal metal recycling (scrap metal recycling, SMR), or even illegally exported for treatment in other countries. Figure 2b shows the percentages of EEE discarded after first use diverted to each of these informal collection routes for both households and non-households.

End-of-life treatment is highly dependent on the way WEEE is collected. Of WEEE being formally collected from households and non-households, it was found that 91.6% was recycled. By contrast, the majority of WEEE thrown away into residual waste & DMR bins, 92.6%, was incinerated (with energy recovery), versus only 4.8% being recycled. Fly tipped WEEE also predominantly entered incineration with energy recovery (65.7%), while 28.8% was recycled. These results underline that the collection pathway is a major determinant of whether discarded EEE enters a circular or linear economy.

The dominant product categories also varied across second-use and treatment pathways (see Table 1). Large household appliances (LHA) were the leading category entering reuse, recycling and legal export pathways. Small household appliances (SHA) were prominent in

consumer and high-street repair, whereas IT and telecommunications equipment dominated in producer repair, recycling, incineration with energy recovery and landfill. Cooling appliances containing refrigerants were considerable in remanufacturing and both in legal and illegal exports.

Table 1 – Top 3 product categories directed to each second-life use, WEEE generated and end-of-life treatment route in London, in 2024.

Pathway	First	Second	Third
Reuse	1. Large Household Appliances (82.7%)	11. Display equipment & 7. Toys, leisure and sports equipment (5.1%)	2. Small Household Appliances (3.6%)
Consumer repair	2. Small Household Appliances (50.9%)	1. Large Household Appliances (15.3%)	4. Consumer equipment (10.4%)
Producer repair	3. IT & Telecom equipment (31.2%)	2. Small Household Appliances (15.1%)	4. Consumer equipment (12.5%)
High-street repair	2. Small Household Appliances (49.4%)	3. IT & Telecom equipment (15.8%)	6. Electrical & electronic tools (12.2%)
WEEE generated	1. Large Household Appliances (33.7%)	3. IT & Telecom equipment (13.1%)	12. Cooling equipment (11.7%)
Remanufacture	12. Cooling equipment (30.0%)	1. Large Household Appliances (27.6%)	11. Display equipment (11.3%)
Recycling	1. Large Household Appliances (25.6%)	2. Small Household Appliances (24.7%)	3. IT & Telecom equipment (17.3%)
Incineration with energy recovery	3. IT & Telecom equipment (29.4%)	2. Small Household Appliances (21.3%)	6. Electrical & electronic tools (11.2%)
Incineration without energy recovery	1. Large Household Appliances (39.1%)	11. Display equipment (20.3%)	4. Consumer equipment (18.0%)
Landfill	3. IT & Telecom equipment (28.4%)	2. Small Household Appliances (20.6%)	6. Electrical & electronic tools (11.3%)

Exports (legal)	1. Large Household Appliances (32.7%)	12. Cooling equipment (27.8%)	11. Display equipment (9.7%)
Illegal exports	12. Cooling equipment (51.0%)	1. Large Household Appliances (32.7%)	11. Display equipment (17.8%)

Three intervention levers were applied to household EEE, based on the dominant contribution of households in consumption of EEE and WEEE generation (see Table 2). To model the potential of second-life strategies to displace the purchase of new equipment, lever 1 increased reuse rates, and lever 2 increased repair. Under the lever 1, the share of household EEE placed on the market that subsequently entered reuse increased from a baseline of 14.2% to 18.2% in the moderate scenario and to 22.2% in the ambitious scenario. Increasing reuse was expected to reduce consumption of new EEE by 4% and 8% in moderate and ambitious scenarios, respectively. For lever 2, the corresponding repair rate increased from 5.3% in the baseline to 10.6% and 15.1% in the moderate and ambitious scenarios, respectively. Increasing repair could reduce consumption by 2.8% in ambitious scenarios. Lever 3 increased formal collection to divert WEEE from incineration and towards recycling. Increasing formal collection rates in the moderate and ambitious scenarios has the potential to increase recycling rates from 33.8 to, respectively, 38.9 and 48.2k tonnes.

Table 2 – Description of the 3 levers of action for household EEE defined and the corresponding targets within a moderate and ambitious scenario.

Lever	Description	Moderate scenario	Ambitious scenario
1.	Increase the reuse	24.5% of reused EEE as a share of households EEE discarded after fist use, tonnes, *vs* 19.1% in the baseline. Based on [18].	29.9% of reused EEE as a share of EEE discarded after first use, tonnes, *vs* 19.1% in the baseline.

2.	Increase the repair	Repair 10.6% of household EEE at the end of its first use, *vs* 5.3% in the baseline. Based on [18].	Repair 15.1% of household EEE at the end of its first use, *vs* 5.3% in the baseline.
3.	Increase formal collection rates	Collection target: 67.3% of WEEE generated. Recycling rates from 33.8k to 38.9k tonnes.	Collection target: 85% of WEEE generated. Recycling rates from 33.8k to 48.2k tonnes.

Discussion

This study shifts attention away from metrics on WEEE generated and puts a spotlight on the management of large and growing stocks of EEE in urban cities. London's estimated stock was an order of magnitude larger than annual EEE placed on the market, and stocks continue to grow. Although it was not possible to quantify the percentage of the stocks that were not in active use in London, the significantly greater amount of new EEE purchased by Londoners in 2024 (255.6k tonnes), compared to that disposed of (140.4k tonnes), suggests that a considerable amount might lay "dormant". Such behaviour points to the possibility that both people and businesses lack information on how to easily and correctly dispose of their unwanted equipment.[19] Additionally, it is likely that many of this unwanted equipment might be in direct reusable conditions, or requiring only minor repairs.[19] Any effort to promote reuse and redistribution of such EEE has the potential to displace the purchase of new equipment, and promote positive social impacts, tackling appliance poverty and contributing to digital inclusion. Conventional policies which focus on WEEE collection targets based on placed on market overlook both the products already accumulated and the possibility that some remain unused despite retaining functional value. As such, a more comprehensive strategy would combine collection targets for WEEE generated, with improved product traceability (including

Digital Product Passports) to provide evidence on product lifetime, value and recovery opportunities.

Additionally, this study highlights that end of first life is a critical intervention point. The potential positive impact of increasing second-life use of EEE in London is clearly captured by the fact that, in an ambitious scenario, close to 11% of new purchases could be displaced through increase reuse, repair and remanufacture. However, once products are collected and classified as WEEE, opportunities to retain functional value decrease significantly, particularly where product streams are mixed or damaged in transportation or storage, or information needed for higher R pathways are lost. The study finds that second-life use of EEE in London is still relatively low (23.3% of the total EEE discarded after first use), suggesting that CE potential still remains unfulfilled. This indicates a persistent gap between practice and the theoretical waste hierarchy, which prioritises “higher R" strategies such as reduce, reuse and repair above recycling. It is also notable that repair rates are much lower than reuse rates (4.3% versus 19.1% respectively), despite significant attention on Right to Repair (see Figure 2b). Second-use pathways are also largely represented by distributed and market-led activities. Peer to peer marketplaces dominate reuse (93%) and independent high-street businesses accounted for the majority of repair (87.9%). Producer repair and formal preparation for reuse represent much smaller flows. The scenario analysis illustrates the potential opportunity for reuse and repair, but also underlines that current distributed pathways are likely to be sufficient at scale. Improved traceability and pre-waste triage and could help to prevent reusable and repairable products from being routed to recycling and downgraded at end-of-life.

Furthermore, the present study shows that the way in which WEEE is collected has a high influence on the way it gets treated at end-of-life, with the majority of WEEE formally collected being recycled, versus that diverted to informal collection routes, which is most likely to be incinerated. There is a strong case to be made on the rationale to increase formal collection

rates, as this would boost recycling, with potential recovery of critical raw materials, thus strengthening the resilience of the city and the country's EEE supply chain. In fact, when analysing the ambitious scenario for lever 3 which saw a doubling of formal collection rates, the amount of WEEE recycled would increase significantly from 33.8 to 48.2k tonnes.

Another important finding from the present study was that formal collection rates in London are still considerably low. For households, only 34.4% of the total WEEE generated was formally collected, i.e. 36.1k tonnes, whilst 44.8k tonnes was lost through informal collection routes, such as residual waste and DMR or illegal exports. Formal collection itself was divided unevenly between actors. Commercial collections including producer take back schemes, accounted for a much larger share of formally collected WEEE than local authority services (80% versus 20%, respectively). Such results point, once again, to a lack of awareness on the part of both households and businesses on how to correctly dispose of their unwanted EEE, but also to the possibility of a need to intervene in terms of the design of the disposal system to make it easier for both households and non-household to send their WEEE to formal collection routes. It is particularly notable that the majority of non-household WEEE is handled informally or improperly which highlights that non-household waste is a particular blind spot that needs greater policy attention. Improved reporting should also make these pathways more visible.

Finally, the results demonstrate the product heterogeneity of EEE and that policies and interventions must be tailored to particular product characteristics. For example, household stocks and flows are dominated by LHA and cooling appliances, whereas IT and Telecommunications Equipment were more prominent within non-household flows. It is also notable that smaller items such as SHA and IT and Telecommunications Equipment are more likely to be repaired than bulky equipment, however, these items are also more likely to be improperly disposed of in residual waste. The most likely product categories to end their first

life as WEEE are LHA. Prior research has proposed maximising coverage collections of low-value EEE for recycling, while higher-value products need more controlled collection routes that preserve value for reuse, repair and refurbishment.[20] The research also found that both legal and illegal exports are mainly represented by LHA, Cooling Appliances, and Displays; implying that specific measures should be taken to control export of these categories.

Improving urban circularity in EEE sector thus requires coordinated action at several points in the system: managing growing stocks, intervening before products become waste, improving collection pathways and tailoring policy measures to the characteristics of specific product categories. Addressing such measures is expected to reduce demand for new products and to strengthen critical raw material availability by minimising unnecessary and improper disposal of WEEE.[21]

Methods:

Electrical and electronic equipment (EEE) placed on the London market in 2024

EEE is placed on the market either by producers who are compliant with Extended Producer Responsibility (EPR) laws, or by free riders i.e. producers who fail to register and report their products under the Waste Electrical and Electronic Equipment Regulations[17].

1 January – 31 December 2024 was selected as the study timeframe, as this was the latest available year for which there was publicly available data published by the Environment Agency and Department for Environment, Food and Rural Affairs (DEFRA)[13].

Environment Agency data for the **EEE formally placed on the market (POM)** in the UK in 2024[13], both by households and non-households, was used to estimate London's share. For households, scaling for London was done by **population** for categories 3. IT & Telecommunications equipment, 7. Toys, leisure and sports equipment, 8. Medical devices, 10. Automatic dispensers, 11. Display equipment, and 13. Gas discharge lamps and LED, and by

number of households for categories 1. Large Household Appliances, 2. Small Household Appliances, 4. Consumer equipment, 5. Lighting equipment, 6. Electrical and electronic tools, 9. Monitoring and control instruments, 12. Cooling appliances and 14. PVs. For non-household EEE, this scaling was done by **number of VAT businesses**. UK and London population, number of households and of VAT businesses were obtained from the Office for National Statistics.[15,16]

The amount of EEE POM by **free riders** was estimated using the percentages reported by Sayers and Rae (2023)[4] for 2021 (see Table 1 in Supplementary Information). From the input received during structured interviews and workshops held with stakeholders from across the UK (W)EEE system, it was found that the evolution of the amount of EEE POM by free riders is expected to be proportional to the evolution in sales from online marketplaces. Accordingly, the historical sales from e-commerce in the UK between 2021, the year for which Sayers and Rae (2023)[4] reported data on free riders, and 2024, the year of concern of the present study, for electronics was obtained, showing a decrease of 15.6%. The evolution of EEE POM by free riders was then assumed to be approximately proportional to the sales of electronics through online marketplaces, and calculated for 2024, for each of the 14 UK WEEE categories, using:

$$EEE\ POM_{free\ riders,2024} = \%\ EEE\ POM_{free\ riders,2021} \times EEE\ POM_{formal,2024} \times (1 - 0.156)$$

where $\%\ EEE\ POM_{free\ riders,2021}$ corresponds to the percentages from Table 1 in Supplementary Information.

Household and non-household stocks and WEEE generated

Estimation of the amount of EEE stocked in London household and non-households, classified according to 14 UK WEEE categories, follows the methodology recommended by the UNU e-waste Statistics framework.[12]

The amount of **WEEE generated** by households and non-households in London, in 2024, was estimated using:

$$WEEE_{generated}(n) = \sum_{t=t_0}^{n} POM(t) * L^{(p)}(t,n)$$

where $WEEE_{generated}(n)$ is the amount of WEEE generated in evolution year n, $POM(t)$ is the amount of EEE placed on the market in any historical year t, and $L^{(p)}(t,n)$ is the life-time profile for the products sold in historical year t.

$POM(t)$ was obtained from the Environment Agency data for the EEE placed on the UK market between 2007 and 2024. $L^{(p)}(t,n)$ was calculated using a Weibull distribution function, which has been reported as the most suitable to describe discard-based life-time profiles for EEE.[12] Since Weibull distribution parameters of shape and scale are not available for the UK, those reported by Forti, Baldé and Kuehr (2018)[12] for the Netherlands, France and Belgium were used, as consumer behaviour in these economies is expected to be similar to the UK.

The amount of **EEE stocked** in households and non-households was then calculated using the following equation:

$$S(n) = \sum_{t=t_0}^{n} POM(t) - \sum_{t=t_0}^{n} WEEE_{generated}(n)$$

Scaling for London was performed according to the same methodology described above of the amount of EEE formally POM.

Second-life use

EEE reused was considered as EEE that has gone through a first-life use to a second-life use through hand-me-downs, second-hand markets, charity shops, and online marketplaces. Data for the products placed and sold on an online marketplace platform in 2024 was provided by a commercial partner. Knowledge of the company's market share allowed to estimate the total

amount of EEE that went through this type of platforms in 2024. This was considered as the total EEE reused, as the amount that would go through other reuse channels is expected to be small, following the input received from stakeholders during the workshops. Scaling for London was performed either by population, number of households or VAT businesses, following the methodology described for EEE formally POM.

According to the input received from stakeholders from across the entire UK (W)EEE system in the workshops, commercial reuse i.e. by non-households is expected to be negligible.

EEE repair can be either conducted by the producer, or through other channels, such as local repair shops, repair cafes, or even through by the owner, as well as by other intermediaries, without change of the product's ownership. In this study, a distinction is made by repair conducted by the producer – Producer Repair, that conducted through informal channels such as repair shops and cafes – Consumer Repair, and that occurring in high-street specialist shops – High-street Repair. Alternatively, for out-of-warranty EEE, remanufacture can be either conducted by the product's producer, or other non-profit intermediaries, implying change of ownership.

Data from OpenRepair Alliance for **Consumer Repair** by product type, in the UK between January and July 2024, was used to estimate the amount of EEE repaired in London, in 2024. This was done by multiplying the number of products repaired by their average reported weight and organising the products according to the 14 UK WEEE categories, obtaining the total tonnage repaired between January and July 2024. Data for the remaining months was extrapolated from these results. Scaling for London was done by population.

Through interviews conducted with stakeholders from across the value chain, it was estimated that 55% of WEEE formally collected gets repaired by producers for products in-warranty (1-2 years after these are placed on the market). From the Weibull distribution used to study the lifetime of EEE and consequent the calculation of WEEE generated (see household and non-

household stocks and WEEE generated), it is possible to obtain the amount of EEE that is expected to fail during the warranty period (1 – 2 years). Applying the in-warranty percentage of remanufacture (55%) to this amount yields the tonnage of in-warranty WEEE being remanufactured by producers in 2024, i.e. **Producer Repair**. Given the lack of data for remanufacture trends by non-households, the same remanufacture rates were considered for both households and non-households. Correcting the timeframe and the remanufacturing percentage, the same procedure was followed for out-of-warranty WEEE to estimate the amount of **Remanufacture** done by producers. Allocation per category of UK WEEE was assumed to be the same as that observed for WEEE generated in London in 2024. The methodology also assumed that remanufacture of WEEE products by non-producers is negligible, following the input received from stakeholders from across the entire UK (W)EEE system in the workshops organised.

Data collected from North London Repair Voucher Scheme was used to estimate the weight of EEE repaired performed by high-street specialist shops in London, i.e. **High-street Repair**. These include the total number of repairs performed by businesses which sign up to the scheme, and the number and type of products repaired. Multiplying the number of products repaired by the average weight of these products, the tonnes of each product repaired were obtained. Allocation of the products to the respective 14 UK (W)EEE categories, allows to obtain the tonnes repaired by category. Scaling for London was done by population.

Collection of WEEE generated

WEEE in London is **formally collected** either directly by Local Authorities (LA) or by commercial businesses. The Waste Data Flow database[14] collects data on the following types of collections:

- Q10: Tonnes of material collected through kerbside schemes from household sources by LA or its contractors;
- Q11: Tonnes of material collected from commercial, industrial or other non-household sources by LA or its contractors;
- Q12: Tonnes of material collected through kerbside schemes by non-contracted voluntary/community sector from household sources;
- Q14/16: Tonnes of material collected for recycling/reuse at CA Sites operated by LA or its contractors;
- Q17: Tonnes of material collected at bring sites operated by LA or its contractors;
- Q18: Composting / Recycling tonnage collected through any other recycling schemes;
- Q33: Tonnes of materials collected at bring sites operated by voluntary / community sector;
- Q34: Tonnes of material collected for recycling at street recycling bins.

Additionally, Q100 reports the total tonnage of all these sources by final destination treatment facility.

The tonnages of household and non-household WEEE formally collected by LA can be obtained using one of the following equations:

$$WEEE\ collections = \mathrm{Q10} + \mathrm{Q11} + Q12 + Q16 + Q17 + Q33$$

$$WEEE\ collections = \mathrm{Q100} - \mathrm{Q14} + Q18 + Q16 + Q23 + Q34$$

London specific data for 2024 was considered.

Since Waste Data Flow reports their data not according to the 14 UK WEEE categories but allocating WEEE to the following five Large Domestic Appliances, Small Domestic Appliances, TVs & Monitors, Fridges & Freezers, Fluorescent tubes & other light sources, it was necessary to convert the Waste Data Flow categories into the 14 UK WEEE ones. The

correspondence between these two classification systems is presented in Table 2 in Supplementary Information and was estimated using the equations below.

$$\text{LHA} = WEEE_{LDA} + WEEE_{Fridges\ \&\ Freezers}$$

$$\text{SHA} = WEEE_{SDA} \times \frac{WEEE_{generated,SHA}}{\sum_i WEEE_{generated,i}}$$

$$\text{IT \& Telecoms} = WEEE_{SDA} \times \frac{WEEE_{generated,IT\ \&\ Telecoms}}{\sum_i WEEE_{generated,i}}$$

$$\text{Consumer eq.} = WEEE_{Fluorescent\ tubes\ \&\ other} \times \frac{WEEE_{generated,Consumer\ eq.}}{\sum_j WEEE_{generated,j}}$$

$$\text{Lighting eq.} = WEEE_{Fluorescent\ tubes\ \&\ other} \times \frac{WEEE_{generated,Lighting\ eq.}}{\sum_i WEEE_{generated,i}}$$

$$\text{EE tools} = WEEE_{SDA} \times \frac{WEEE_{generated,EE\ tools}}{\sum_i WEEE_{generated,i}}$$

$$\text{Toys, leisure \& sports} = WEEE_{SDA} \times \frac{WEEE_{generated,Toys,leisure\ \&\ sports}}{\sum_i WEEE_{generated,i}}$$

$$\text{Medical devices} = WEEE_{SDA} \times \frac{WEEE_{generated,Medical\ devices}}{\sum_i WEEE_{generated,i}}$$

$$\text{Monitoring \& control inst.} = WEEE_{SDA} \times \frac{WEEE_{generated,Monitoring\ \&\ control\ inst.}}{\sum_i WEEE_{generated,i}}$$

$$\text{Display equipment} = WEEE_{TV\ \&\ Monitors}$$

In the system of equations above, i stands for the categories 2, 3, 6, 7, 8 and 9 of the UK 14 (W)EEE categories, whereas j stands for categories 4 and 5.

To estimate the amount of WEEE collected by commercial businesses, Environment Agency data for total collections in the UK was scaled for London using the same methodology described above for EEE formally POM. After scaling each WEEE category for London, commercial collections were obtained subtracting the WEEE collected by LA to the values obtained.

The amount of **WEEE diverted to residual waste streams and dry mixed recycling** (DMR) was estimated based on a waste compositional analysis conducted by a London Waste

Authority based on 2023-2024 household waste tonnages. The analysis found the occurrence of WEEE in kerbside and flats DMR to be lower than in the residual waste. They reported that WEEE represented 1.08% in weight of the total waste. The total residual waste collected by LAs in London, in 2024, was obtained from WasteData Flow[14].

Scaling for London was performed following the methodology used for EEE formally POM, but considering now the population and households of the boroughs covered by the London Waste Authority in question. WEEE from non-households being directed to residual waste was considered negligible, based on the input received both during structured interviews conducted individually with the project partners, as well as during the MFA workshops.

To estimate the amount of WEEE in residual waste and DMR collected by commercial businesses the amount of municipal waste collected in England in 2023 was used, as this was the most recent data available. These data were scaled to London by population. To this value, the amount of residual waste & dry mixed recycling collected by LA, extracted from WasteData Flow[14], was subtracted, yielding the total amount of residual waste & DMR collected by commercial businesses. It was found that the split between municipal and commercial collections was 54:46. Knowing so, the amounts of WEEE diverted from formally being collected and treated to residual waste streams and DMR for the 14 UK (W)EEE categories, for both households and non-households, were estimated.

In their 2023 report, Material Focus reported that 18.73% of the **WEEE** generated in the UK in 2021 went into **scrap metal recycling** schemes.[4] From the input received during structured interviews conducted with project partners, as well as during the workshops, it was found that the evolution of the amount of WEEE being directed into scrap metal recycling is expected to follow that of the price of metals, particularly steel. The evolution of the price of steel in the UK between 2021, the year for which Sayers and Rae (2023)[4] reported data on WEEE being diverted into scrap metal recycling, and 2023, the year for which the most recent data was

available, shows a decrease of approximately 31%. The evolution of WEEE diverted into scrap metal recycling was assumed to be approximately proportional to that decrease, accounting for a temporal lag in the impacts of the changes in the price of steel. The amount of WEEE diverted into SMR routes, in 2024, was calculated as follows:

$$WEEE_{SMR,2024} = \%\, WEEE_{SMR,2021} \times (1 - 0.31)$$

WEEE treated by metal recyclers can be collected formally, both by LAs and commercial businesses, or informally collected, e.g. "man in a van". Data from WasteData Flow[14]for Q100 was used to obtain the relative percentage of metal recyclers in final destinations of WEEE formally collected by LA. Multiplying WEEE formally collected by LA by this percentage, the amount of WEEE formally collected by LAs and treated by metal recyclers was obtained. The same percentage and procedure were adopted to estimate the amount of WEEE formally collected by commercial businesses. Informal collection of WEEE for SMR was calculated as the difference between the total amount of WEEE diverted into SMR routes, $WEEE_{SMR,2024}$, and the sum of WEEE formally collected by both LA and commercial businesses and treated by metal recyclers.

The HMRC publishes data on overseas trade classified according to the Harmonised System (HS). Using the HS code *8549 – Electrical and electronic waste and scrap*, the total amount of WEEE exported to EU and non-EU countries by the UK in 2024 can be obtained. This value corresponds only to **legal exports**, all from formal WEEE collection. Scaling for London was done by populations. Using the WEEE collection ratios to allocate the amounts of each WEEE category, the amount of WEEE legally exported from London was calculated.

Illegal exports tonnages were obtained considering values from the Global Transboundary E-waste Flows Monitor 2022. According to the UN Global E-Waste Monitor 2024[1], and based on the Global Transboundary E-waste Flows Monitor 2022[22], 65% of the e-waste shipped

across borders is illegally exported. Allocation per category was assumed to be the same as that observed for legal exports.

The amount of WEEE that is disposed of through **fly tipping** was estimated based on a compositional analysis conducted by a London Waste Authority. The analysis found that WEEE accounted, on average, for 2.34% of fly tipped material, ranging from 0.03% to 6.5% between boroughs. Table 3 in Supplementary Information summarises the percentage of WEEE fly-tipped allocated to the 14 UK categories. The total amount of fly tipped material was extracted from WasteData Flow[14], for London in 2024.

Scaling for London was performed according to the methodology used for EEE formally POM, but considering now the population and households of the boroughs covered by the London Waste Authority in question. WEEE from non-households being directed to residual waste was considered negligible, based on the input received during structured interviews and MFA workshops.

End-of-life

The total amount of WEEE formally collected that is either recycled, sent to landfill or incinerated (with or without energy recovery) was obtained from Waste Data Flow. Conversion from the Waste Data Flow categories into the 14 UK WEEE ones followed the procedure described in the WEEE generated section for WEEE collection. For each end-of-life pathway, dividing each category weight, obtained by solving the equations system, by the total amount treated gives the percentage of each WEEE category.

The amount of WEEE collected through residual waste that is either recycled, sent to landfill, incinerated (with or without energy recovery) or treated through another end-of-life option was estimated from data published by DEFRA on the management of all LA collected waste.[12] The

provisional results for London, in 2023 – 2024 are shown in Table 4 in Supplementary Information. For each of the 14 UK (W)EEE categories, the amount collected through Residual Waste streams was multiplied by the percentages from Table 4 in Supplementary Information to obtain the amounts treated by each of the five end-of-life pathways.

The methodology employed to estimate amount of WEEE fly tipped that was sent for recycling, to landfill, incineration (with or without energy recovery) or treated through another end-of-life pathway was estimated using the procedure described for WEEE in Residual Waste. For each of the 14 UK (W)EEE categories, the amount WEEE fly tipped was multiplied by the percentages from Table 4 in Supplementary Information to obtain the amounts treated by each of the five end-of-life pathways.

Levers of action

Lever 1: Increase the reuse of household EEE to displace new purchases

The moderate scenario considered an increase of the EEE reused by households as share of POM from 14.2% (baseline value from London's 2024 MFA) to 18.2%, while in the ambitious scenario that value would reach 22.2%. Considering 50% of potentially reusable WEEE based on WRAP[18] estimates of (W)EEE in reusable condition, and assuming a 1:1 displacement rate of POM (i.e. from every item reused, one item was diverted from POM), the moderate scenario would enable the reuse of 8k tonnes of EEE. Assuming the same displacement rate, but 100% of potentially reusable EEE being diverted from waste, 16.2k tonnes of EEE would be reused in the ambitious scenario.

Lever 2: Increase the repair of household EEE to extend product lifespans

An increase in repair from the MFA baseline value of 5.3% to 10.6% and 15.1% was considered in the moderate and ambitious scenarios, respectively. These values were estimated based on

those from WRAP[18] for diverted EEE in need of slight and major repair: the **moderate scenario** considered the repair of 100% of diverted EEE in need of **slight repair**, whereas the **ambitious scenario** considered the repair of 100% of EEE in need of **slight and major repair**. A 1:2 displacement rate for POM was assumed for both i.e. for every two items repaired, 1 item was diverted from POM.

Lever 3: Increase formal collection rates for household EEE to increase recycling

In London, in 2024, 44.7% of the household WEEE discarded after first use was formally collected, corresponding to approximately 36.1k tonnes. A collection target of 67.5% WEEE generated was considered in the moderate scenario, in line with the current reported best practice in the EU.[23] The current EU taxonomy which sets a target of formal WEEE collections rate of 85% of the WEEE generated was adopted for the ambitious scenario.[23]

Data Quality Statement

Data Quality Indicator (DQI) matrix was employed to assess reliability of the source, data representativeness, temporal correlation, geographical correlation, and technological correlation. This can be found in Table 5 in Supplementary Information.

The assessment indicated that the reliability of the data sources was generally **good**, since majority of the data were obtained from verified data partly based on assumptions. **Geographical correlation** was also rated as **good**, indicating that the datasets adequately represent the geographical context of the study.

The **temporal correlation** of the data was assessed as **good** to **very good**, as the data used in the study always referred to periods that deviated by less than 6 years from the year under study period of the assessment (2024). **Data representativeness** was rated as **good** to **fair**, as some

data was scaled from a smaller number of sites and adequate or shorter periods. **Technological correlation** ranked very **good**.

References:

1. Baldé, C.P., Kuehr, R., Yamamoto, T., McDonald, R., D'Angelo, E., Althaf, S., Bel, G., Deubzer, O., Fernandez-Cubillo, E., Forti, V., Gray, V., Herat, S., Honda, S., Iattoni, G., Khetriwal, D.S., Luda di Cortemiglia, V., Lobuntsova, Y., Nnorom, I., Pralat, N., & Wagner, M. (2024). *International Telecommunication Union (ITU) and United Nations Institute for Training and Research (UNITAR). 2024. Global E-waste Monitor 2024*. Geneva/Bonn. Available here: https://ewastemonitor.info/the-global-e-waste-monitor-2024/. (Accessed July 2026).
2. Bond, M. (2022). *The Carbon Footprint of WEEE (Waste Electronic and Electrical Equipment) in the UK–a case study based on the UK's largest WEEE producer compliance scheme*. Master's thesis. Lancaster University, UK.
3. Sayers, M., and Peagam, R. (2020*). Electrical Waste - Challenges & Opportunities: An independent study on Waste Electrical Electronic Equipment (WEEE) flows in the UK. Final Report*. Material Focus
4. Sayers, M., and Rae, E. (2023). *Electrical Waste: Challenges & Opportunities 2023*. Final Report. Material Focus
5. Hu, X., & Yan, X. (2023). *Estimation of critical metal consumption in household electrical and electronic equipment in the UK, 2011–2020*. Resources, Conservation and Recycling, 197, 084.
6. Kahhat, R., & Williams, E. (2012). *Materials flow analysis of e-waste: Domestic flows and exports of used computers from the United States*. Resources, Conservation and Recycling, 67, 67-74.
7. Lau, W. K. Y., Chung, S. S., & Zhang, C. (2013). *A material flow analysis on current electrical and electronic waste disposal from Hong Kong households*. Waste management, 33(3), 714-721.

8. Ismail, H., & Hanafiah, M. M. (2021). *Evaluation of e-waste management systems in Malaysia using life cycle assessment and material flow analysis*. Journal of Cleaner Production, 308, 127358.
9. Biganzoli, L., Falbo, A., Forte, F., Grosso, M., & Rigamonti, L. (2015). *Mass balance and life cycle assessment of the waste electrical and electronic equipment management system implemented in Lombardia Region (Italy)*. Science of the Total Environment, 524, 361-375.
10. UK Government. (2023). *Electrical and electronic equipment (EEE) covered by the WEEE Regulations*. Available here: https://www.gov.uk/government/publications/electrical-and-electronic-equipment-eee-covered-by-the-weee-regulations/electrical-and-electronic-equipment-eee-covered-by-the-weee-regulations/. (Accessed March 2025).
11. Arora, R., Paterok, K., Banerjee, A., & Saluja, M. S. (2017). *Potential and relevance of urban mining in the context of sustainable cities*. IIMB management review, 29(3), 210-224.
12. Forti V., Baldé C.P., Kuehr R. (2018). *E-waste Statistics: Guidelines on Classifications, Reporting and Indicators*. 2nd Edition. United Nations University, ViE – SCYCLE, Bonn, Germany.
13. UK Government. (2026). *Waste electrical and electronic equipment (WEEE) in the UK*. Business and industry. Business and the environment. Statistical data set. Available here: https://www.gov.uk/government/statistical-data-sets/waste-electrical-and-electronic-equipment-weee-in-the-uk. (Accessed August 2026).
14. WasteDataFlow. Available here: https://www.wastedataflow.org/ . (Accessed August 2026).

15. Office for National Statistics. (2021). Population. Available here: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates . (Accessed March 2025).
16. Office for National Statistics. (2024). *London*. Available here: https://www.ons.gov.uk/explore-local-statistics/areas/E12000007-london. (Accessed July 2026).
17. UK Government. (2025). *The Waste Electrical and Electronic Equipment (Amendment, etc.) Regulations 2025*. Available here: https://www.legislation.gov.uk/ukdsi/2025/9780348272512 . (Accessed July 2016).
18. WRAP. (2011). *Realising the Reuse Value of Household WEEE*. Available here: https://silo.tips/download/realising-the-reuse-value-of-household-weee . (Accessed June 2026).
19. Abdelmeguid, A., Corsini, L. (2026). *A Circular Economy for Electrical and Electronic Equipment: Insights from UK Stakeholders Across the Value Chain*. In: Jolly, M., Scholz, S.G., Howlett, R.J., Setchi, R. (eds) Sustainable Design and Manufacturing 2025. KES-SDM 2025. Smart Innovation, Systems and Technologies, vol 483. Springer, Cham. https://doi.org/10.1007/978-3-032-21469-0_27 .
20. Abdelmeguid, A., and L. Corsini. (2026). *Barriers and Enablers of Circular Economy in Electrical and Electronic Equipment: A Systematic Literature Review*. Business Strategy and the Environment 1–34. https://doi.org/10.1002/bse.70559.
21. Outeirinho Morgado, A., Corsini, L., Russel, M., Shairp, R., Singer, R., & Metivier, P. (2026). *London's electricals and electronics footprint: An analysis of material flows, greenhouse gas emissions and levers for action in London*. ReLondon.

22. C.P. Baldé, E. D'Angelo, V. Luda O. Deubzer, and R. Kuehr (2022), *Global Transboundary E-waste Flows Monitor – 2022*. United Nations Institute for Training and Research (UNITAR), Bonn, Germany.

23. European Environment Agency. (2025). *Waste electrical and electronic equipment (WEEE) collection rate (Indicator)*. Available here: https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/waste-electrical-and-electronic-equipment-weee-collection-rate-indicator . (Accessed June 2026).

Supplementary Files

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