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Quantifying used electrical and electronic equipment exported from Ireland to West Africa in roll-on roll-off vehicles

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**ABSTRACT**

The investigation on the transboundary shipment of used and waste electrical and electronic equipment from developed countries is a well-studied subject with regard to the environmental and health impacts in the destination countries when it reaches end-of-life. Prior research has ranked Ireland the 8th highest source of used electrical and electronic equipment (UEEE) into Nigeria, with roll-on roll-off (RoRo) vehicles as the largest carrier (Odeyingbo 2017). This study presents the first comprehensive port of origin estimation of UEEE export shipments from Ireland in RoRo vehicles. This was obtained by using a `person in the port` involving vehicle and enforcement document inspections at the Ringaskiddy port in Cork, Ireland. By scaling sampling data to annual shipment figures, it was estimated that 17,319 kg of UEEE are currently exported from Ireland annually and that around 1 in 5 vehicles exported contain UEEE. Additionally, the type of UEEE and frequency of shipments show certain equipment are high in demand at destination country. By using the Nigerian second-hand websites, the annual shipments were valued at approximately €147,225. The results obtained from this study suggests a significant reduction in UEEE exported from previous studies and highlights an opportunity for further research in additional ports of origin, as well as the examination of the shipping process, cost, and verification of functionality. Additionally, the straightforward methods provide better understandings of UEEE flows as this is significant to all stakeholders concerned with the regulation, enforcement, and safety of UEEE shipments.

1. Introduction

Increased demand, high obsolescence rates, innovation, and shorter product lifespans contribute to the growth of discarded electrical and electronic equipment (EEE) (Baldé et al., 2015a; Perkins et al., 2014). Popularly referred to as the fastest growing solid waste stream, around 50 million metric tonnes (t) of waste EEE (WEEE) is generated globally at an estimated 6 kg per person, projected to rise to up to 111 million tonnes per annum by 2050 (Parajuly et al., 2019). The high generation of WEEE and its effects on resource depletion, ethical concerns, health, and environmental degradation necessitate the rising concern and regulatory focus around WEEE treatment (Ongodo et al., 2011).

In particular, the transboundary flows of both used electrical and electronic equipment (UEEE), shipped for the purpose of reuse, and the often-illegal shipments of WEEE are a focal subject of growing research (Song et al., 2017). The export of both WEEE and UEEE from developed countries to developing countries, with China, India, Pakistan, and Nigeria being leading destinations (CucchIELla et al., 2015; SthiannopkaO and Wong 2013), has the potential to undermine set collection and recycling targets as the materials are no longer available for treatment where they were originally placed on the market. For instance, only 22% of generated wastes in the USA is collected where European countries collect up to 35%, and 16% was exported, largely in undocumented exports (Parajuly et al., 2019; Baldé et al., 2017). Furthermore, with the present focus on advancing a circular economy, the transboundary shipment of WEEE may lead to a loss of materials recoverable by advanced recycling end processing, which the destination countries may lack. However, communities in developing countries may also experience benefits in access to equipment and quality of life from the import of non-waste UEEE (Sections 2.1 and 4.5).

Recent research indicated that the United States (US), China, and six European Union (EU) countries (Germany, the United Kingdom (UK), Belgium, Netherlands, Spain, and Ireland) are responsible for the import of the largest amount of used electronics to Nigeria. Subsequently, this research ranked Ireland as the 8th highest exporter of used electronics, contributing a share of 6.15% of imports, over 98% which was imported via roll-on roll-off (RoRo) shipments (Odeyingbo et al., 2017; 2019). For this reason, the scope of this study has focused on RoRo shipments. The term `RoRo` shipments, used throughout the remainder of this paper, refers to cargo shipments where individual, whole
vehicles and their contents are driven on and off cargo vessels, unlike container shipments where items are loaded into a container then transferred onto vessels.

Discussed in Sections 2.1 and 2.2, data quantifying the transboundary movements of UEEE and WEEE, particularly from origin ports, is limited in academic literature. Methodologies used where this subject does appear are often unclear, and no consistent standard has been used to determine these numbers, a discussion also presented in Odeyingbo et al. (2019). This research seeks to generate uniquely primary, on the ground data on the quantities of UEEE exported from Ireland, particularly UEEE contained in RoRo vehicle shipments, and also examines the financial factors driving these exports. The resulting quantitative data provides a deeper understanding of transboundary shipments of UEEE from Ireland to other countries, especially developing nations. This is important as well-collated data reduces the generation of e-waste, prevents illegal shipments, promotes recycling, creates green jobs, and curbs global emissions (Baldé et al., 2017). Furthermore, at a national level, the lack of quantification of transboundary movements of UEEE and WEEE creates difficulty in addressing issues such as proper estimation of collection and recycling in order to meet legislative targets (Forti et al., 2020).

The main objective of this study is the inspection of RoRo vehicles for the purpose of quantifying used electronics prior to shipment. This involved an investigation on the types of UEEE contained in the vehicles and a quantitative analysis of the volume. The research also goes further to estimate the value of shipped UEEE in the Nigerian online reuse market. The following sections will outline these investigations through an examination of the existing literature, particularly relating to the generation and flows of used and waste electronics, an explanation of the adapted person in the port methodology undertaken in quantitative analysis of used electronics in RoRo exports, and the results of these estimations, as well as conclusions drawn from the key findings.

2. Background

In both literature and practice, the distinction between UEEE and WEEE can often be quite difficult to determine, and the transboundary movement of WEEE disguised as UEEE contributes to this difficulty (Song et al., 2017; Li et al. 2013). UEEE is defined as EEE that, although used, is still workable in its original form, or can be repaired, modified, or reconditioned for use in the same original purpose it was designed for (Odeyingbo et al., 2017). WEEE refers to EEE, inclusive of its parts, that has been discarded by the owner as waste without the intention of reuse (StEP Initiative 2014). In the context of this definition of WEEE, one may assume that the reason discard arises from defect or lack of functionality, however, this varies, as the reason for disposal has been reported as anything ranging from age to a need for newer and ‘trendier’ models (StEP Initiative 2014). Therefore, EEE does not need to be non-functional to be deemed waste and this highlights the subtle and thin line between used electronics and waste electronics.

2.1. Export of ugee to west africa

Presently, growing reuse policies and innovative initiatives such as collection events are promoting the reuse market in developed countries (Coughlan and Fitzpatrick 2020). Additional initiatives in developed nations, such as Computers for Schools in Canada and businesses such as Camara and Green IT in Ireland, provide low cost refurbished equipment to meet the existing demand for affordable electronics in groups such as schools and individual students, for whom these products might not otherwise be accessible. However, substantial price differences have been shown to not deter many individual consumers in developed countries from favouring new electronics, whereas the opposite remains the case in developing countries (Williams et al., 2008). Due to such disparities in economic situations, discarded electronics often find high reuse value when shipped to developing regions. Equipment often holds economic and/or use potential for other individuals or communities, especially those in developing countries where the lower cost reuse market improves access to information and communication technology (ICT) (Williams et al., 2008). The demand for UEEE in developing countries such as Nigeria is on the rise. Even with the infiltration of new EEE at cheaper rates from countries like China, the demand still exists as source of this UEEE is a factor. Consumers tend to favour UEEE from Europe, popularly referred to as ‘UK used’, ‘tokunbo’, or ‘second-hand electronics’ in Nigeria. With the current growth in ICT, the demand for these will grow. This supports findings by Kahhat and Williams (2009) suggesting that used computers exported from developed countries to developing countries (in this case Peru), are intended for direct reuse as opposed to recycling.

While local generation of e-waste in West African countries is rising (Forti et al., 2020), imports contribute largely to the numbers. West Africa serves as a major trading route of used electronics, with Ghana and Nigeria being main import hubs for equipment shipped in containers and RoRo vehicles to Lagos, Tema, and Benin (Secretariat of the Basel Convention 2011; UNEP 2015; Asante et al., 2012). Over time, attempts have been made to quantify the amount of UEEE/WEEE imported into West Africa, especially Nigeria and Ghana, but often the methodologies employed in these studies have limitations in replicability and consistency in terms, discussed further in Section 2.2. The Digital Dump report by Basel Action Network (2005) estimates that around 400,000 used computer scraps are imported into Nigeria monthly in containers. However, the methods for estimating numbers in this report are not shared in depth, as they were not the focus. By using logistic modelling and material flow analysis, Yu et al. (2010) estimates that the growth of obsolete personal computers (PCs) in developing countries will increase to 400–700 million units, compared to 200–300 million units in developed countries. As mentioned in Section 1, research by Odeyingbo et al. (2017) identified Ireland as a significant contributor to UEEE and WEEE entering the studied port in Nigeria, with an estimated 3,660t of UEEE arriving in Ireland in RoRo vehicles and 40t in container imports (Odeyingbo et al., 2017). During the period of assessment, 105 of 170 imported vehicles were observed to contain UEEE. Of these shipments, items imported consisted mostly of screens, large equipment, and small appliances, of which 60% was reported clean and suitable for direct reuse, and 40% improperly packaged and dirty (Odeyingbo et al., 2017).

Studies by Bisschop (2012); Lepawsky (2014; 2015), and Amankwah-Amoah (2016a; 2016b) emphasise the push factors, or the drivers that move WEEE from source countries, and pull factors, the attractants from destination countries, in the transboundary shipment of UEEE. Together these factors provide the motives and actors influencing the transboundary flows of UEEE/WEEE (Bisschop 2012). Push factors include recycling costs and regulatory constraints while pull factors from destination countries include factors such as trade and access to improved EEE (Amankwah-Amoah 2016b). Several studies have attributed the exports of WEEE from developed countries to stem from push factors. It is argued that WEEE is illegally exported to developing countries under the guise of humanitarian aid or UEEE to bridge the digital gap (Cucchiella et al., 2015).

While examination of the methodologies is often met with similar limitations to those mentioned earlier in this section, additional studies highlight the pull factors, such as how the pathways of UEEE from formal to informal sectors are facilitated by brokers and traders (Secretariat of the Basel Convention 2011). These range from small, family-based networks to large trading firms. This sector is largely driven by immigrants or temporary residents from African countries engaged in creating trading businesses serving the European-African routes (Secretariat of the Basel Convention 2011). Findings from the Basel Convention E-waste Africa Programme equally show that about 150,000 tonnes of UEEE is imported into Ghana annually. Of that amount, 15% was repaired and resold while the other 15% was irreparable. In Nigeria, of the 100,000 tonnes UEEE imported into the
country illegally in 2010, 30% was non-functional (Ogunbuyi et al., 2012). Such imports have led to a flourishing industry of informal recycling in West Africa (UNEP 2015). In addition to imports, the growing demand for new ICT in developing countries contributes to the increasing numbers of locally generated WEEE, and with the correlation between growth of gross domestic products (GDPs) and generated WEEE, the numbers will see up to a threefold increase by 2050 (Parajuly et al., 2019).

Illegal and unlicensed exports of WEEE to developing countries with ineffective recycling results in the loss of valuable metals like palladium, gold, silver, indium, and germanium (Secretariat of the Basel Convention 2011). However, the trade of imported UEEE in good condition has the potential to provide significant socio-economic value. Still, the major challenge remains to be the import of e-waste and near end-of-life equipment (UNEP 2015). Furthermore, with the markets for reuse and the provision of jobs via preparation for reuse, there is potential for decent work creation and economic growth. Although the methodologies for job estimation are frequently not clear, e-waste is suggested to create employment in developing nations. In Ghana, e-waste has been suggested to employ 25,000 people and sustain around 200,000 (Lundgren 2012). Similarly, in Nigeria, the refurbishment and repair sector on both imported and domestic generated UEEE generates income for more than 30,000 people (Secretariat of the Basel Convention 2011). The opportunities in the processing and trade of UEEE such as computers offers a high degree of reuse, employment, and, in the long run, provides socio-economic benefits due to factors such as increased accessibility to technology for low-income earners (Kahhat and Williams 2009).

On the other hand, the consequences can be severe as outlined in Section 1, where this is inefficiently handled as often seen in developing countries. In Agbogbloshie dump in Ghana, where informal recycling is carried out, skin diseases, respiratory problems, chronic nausea and serious headaches are amongst the common ailments recyclers suffer (Yeung 2019). Also, elevated levels of iron, antimony, and lead were found in the urine of e-waste recycling workers in Accra (Asante et al., 2012). In Nigeria, the improper management of e-waste such as inappropriate disposal has led to it being termed a ‘deadly time bomb’ as the soil and water surrounding dumpsites of e-waste are highly contaminated (Ojewale 2018).

2.2. Quantitative characterisation of used and waste electronics exports

It is argued that despite the amount of reporting on the transboundary shipment of UEEE/WEEE, a majority of sources fail to employ scientific methods or give empirical data (Song et al., 2017; Miller et al., 2012). Some of the factors responsible include challenges in collecting data such as limited mechanisms, undifferentiated trade codes, and a lack of consistent definitions of categories and labels (Song et al., 2017; Miller et al., 2012). Other factors include the lack of a universal definition of e-waste, the absence of trade data that clearly distinguishes new EEE from used EEE, and the role of illicit trade (Lepawsky 2015; Bisschop 2012). It is argued that the presence of quantitative figures significantly aids the understanding of the issues surrounding the transboundary shipment of e-waste (Breivik et al., 2014; Miller et al., 2012). Indeed, statistics measuring e-waste like those reported in this paper are a necessary step toward addressing this challenge, helping to assess targets, explore best practices, and improve policies (Baldé et al., 2017).

Miller et al., (2012) evaluates several approaches and data sources used to quantitatively characterise the transboundary shipment of UEEE including electronic tracking, person in the port, trade data, custom and shipment data/documents, material flow analysis, sales data, mass balance, handler surveys, and enforcement data. Another approach incorporates a combination of methods such as the person in the port approach and evaluation of shipment records as seen in Oderyngbo et al., (2017). It is reasoned that the use of trade data and proxy trade data rank low as the methodologies applied contain flaws that hinder the production of reliable statistics (Forti et al., 2018). Limitations on the use of trade data in many countries include a lack of differentiation between new and used electronics, definitional challenges, and difficulty in ascertaining functionality of equipment (Miller et al., 2012). The use of enforcement data, handler surveys, and surveillance from inspections require moderate efforts and the quality of the information is deemed medium-high. Other methodologies such as electronic tracking, person in the port, and material flow monitoring are ranked high as these require significant efforts and the approach is thorough (Forti et al., 2018; Miller et al., 2012).

In the characterisation of used and waste electronics, several types of classification have been adopted in the past such as the use of Harmonised Commodity Description and Coding System (HS) codes. Although, this is unsuitable for the measurement of exports as the codes are not particular to e-waste and fails to distinguish between new and used EEE (Forti et al., 2018; Baldé et al., 2015b).

To harmonise e-waste statistical data and classification, the UNU-Keys were introduced by the United Nations University (UNU) and classify EEE by similar functions, material composition, average weights and the fate of the EEE at end-of-life (Baldé et al., 2015b). The UNU-Keys classification system encompasses all EEE broadly grouped under 54 categories (Baldé et al., 2015b). Furthermore, this system of classification removes discrepancies encountered in the representation of e-waste statistics between official data and academic data. To date, this is the most reliable classification and has been employed in several high-profile studies published by the UNU, such as the Global E-waste Monitor by Baldé et al., (2017), and has been used for the research described in this paper.

2.3. Regulations on transboundary shipment of weee

Presently, many developing countries lack effective legislation and infrastructure required for efficient management of solid waste, including WEEE (Parajuly et al., 2019). This inadequate management of WEEE has led to a plethora of health and environmental challenges in developing countries. Findings from a systematic review on the health consequences of exposure to e-waste by Grant et al., (2013), show that workers and people living in towns where WEEE is poorly managed are prone to grave health complications such as changes to thyroid function and cellular expression and function, DNA mutations, and decreased lung function.

The principal regulations prohibiting transboundary movements of hazardous waste, particularly from Europe, are the Basel Convention, the Organisation for Economic Cooperation and Development (OECD) council decision (2001) 107/FINAL, and the European Waste Shipment Regulation (Milovantseva and Fitzpatrick 2015). Following prominent cases of the transboundary shipment of waste from developed to developing countries in the 1980s, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 and came into force in 1992. To date, 187 countries are signatories to this treaty; Haiti and the US are yet to ratify or transpose this into national laws. The principal aim of the Basel Convention is to protect human and environmental health against the adverse effects of hazardous waste by limiting its generation and strictly regulating and restricting its movement across borders.

The OECD Decision C (92)39/FINAL, on the Control of Transboundary Movements of Wastes Destined for Recovery Operations, revised in 2002, regulates the movement of e-waste between OECD member countries. Based on two types of risk categories (green and amber control procedures), the cross-border movements of wastes are controlled. Green control procedure monitors wastes with low risk to human and environmental health while amber monitors wastes that present higher risks. The WEEE Directive is the principal regulation on the management of household and non-household WEEE in the EU (Forti et al., 2018; Milovantseva and Fitzpatrick 2015). Established as an extended producer responsibility (EPR) directive, the Directive promotes the reuse, recycling, and recovery of WEEE by minimising disposal of WEEE in unsorted municipal waste (Johnson and Fitzpatrick 2016; Shiannopka and Wong 2013). The recast WEEE Directive published
in 2012 introduced key changes including more ambitious collection targets, increases in recovery targets, a reorganisation of the scope of EEE (i.e., temperature exchange equipment, screens and monitors, lamps, large equipment, small equipment, and small IT and telecommunication devices) and the implementation of free take-back of small household appliances (Johnson and Fitzpatrick 2016).

2.4. Enforcement of weee regulations in Ireland

In Ireland, Statutory Instrument (S.I.) No. 149 (2014) ratified the WEEE Directive into national law. The Environmental Protection Agency (EPA) Office of Environmental Sustainability is responsible for the regulation of WEEE in Ireland (Johnson and Fitzpatrick 2016). In 2017, Ireland surpassed the 45% target for collection of WEEE by collecting 51% of EEE placed on the market three years prior (Environmental Protection Agency 2019). However, new targets set from 2019 require an increase from 45% of EEE placed on the market to 65% of equipment sold. Such ambitious targets present a challenge for Ireland and other EU member states.

The National TransFrontier Shipment Office (NTFSO) of the Dublin City Council, established in July 2007, is the national authority on the regulation of exports, imports, and transit of waste shipments in Ireland. Formerly, enforcement and regulation of exports was conducted by local authorities, resulting in a fragmented approach to requirements and reporting. The consolidation of authority in the NTFSO allowed for consistency in the regulation and enforcement of WEEE, considered a priority waste (Johnson and Fitzpatrick 2016), and other waste transit. The Waste Regulation and Enforcement unit of the NTFSO is charged with the management of waste shipments including WEEE. To ensure that UEEE shipped in RoRo vehicles from Ireland is for direct reuse, a series of procedures and inspections in line with WEEE. To ensure that UEEE shipped in RoRo vehicles from Ireland is for direct reuse, a series of procedures and inspections in line with WEEE, the vehicles themselves are inspected for road worthiness and safety of contents, particularly auto parts. Vehicles with verifiable, complete, and accurate documentation are cleared for shipment. Vehicles lacking one or more of these requirements are placed on hold and will not be shipped until such time that the discrepancies are addressed.

3. Research methodology

The use of a quantitative research method using a person in the port approach, which combined with the evaluation of export documents provides a more complete overview on e-waste shipments (Forti et al., 2018), was applied for this research. As discussed in Section 2.2, this has been suggested as the best approach to evaluate flows of used electronics. The use of quantitative research methods ensures that robust estimates of UEEE are attained (Miller et al., 2012). The adoption of this method allows for the data collected in this study to accompany data obtained through previous uses of the person in the port approach for quantifying exports of UEEE, The quality of data from the research methods used is highly regarded due to the high level of effort undertaken for the study (Miller et al., 2012).

3.1. Area of study

The Ringaskiddy port in County Cork is located in the south-western part of the Republic of Ireland. Ringaskiddy is reported by shipment authorities to be the only major route for the export of RoRo vehicles, with largely insignificant flows of RoRo vehicles leaving other ports in the Republic of Ireland. However, further research could be conducted to verify and examine flows at other ports. The export compound for RoRo vehicles serves as the receiving location for owners to drop off vehicles to be shipped, secure storage of vehicles awaiting shipment, and the location of compliance inspections prior to shipment (Fig. 3.1).

3.2. Data sources and collection

As suggested by the Person in the Port research by Odeyingbo et al., (2017), RoRo vehicle shipments from Ireland serve as the principal route for the movement of used and waste EEE (Section 1). Based on this research, as well as interviews with waste enforcement and port officials confirming that RoRo vehicles, rather than containers, were the main carriers of UEEE, RoRo vehicles were chosen as the focus of observational inspections.

The research scope covers all categories of EEE listed within Annex IV of the recast WEEE Directive.

![Fig. 3.1. RoRo vehicles to be inspected at the export compound in Ringaskiddy port, Cork.](image-url)
The research team was granted access to the shipment yard by NTFSO to accompany waste enforcement officers for the existing once-monthly, on-site inspections of RoRo vehicles in the export compound. The research was conducted between June 2019 and March 2020, and accounted for approximately every other shipment of vehicles, as shipments leave on average twice monthly according to the shipping company. On inspection days, despite compliance inspections being conducted on a random selection of vehicles, the research team collected data on the presence of EEE and attached enforcement documents for every vehicle present.

A visual inspection of each vehicle to confirm that documentation, outlined in Section 2.4 and Appendix A, reasonably represented the content completed. Vehicles whose packing lists were found by waste enforcement officers to be not accurately representative of the contents, or vehicles containing equipment but lacking a packing list, were stopped by inspectors until cleared with the appropriate paperwork. These vehicles were marked noncompliant in the data collection, as they were on hold and not being shipped at the time of data collection.

Each vehicle was given a unique identifier upon sampling in order to prevent duplicates in the data. Unique identifiers and the collected data associated with each were then collated and analysed to ascertain quantities. Preventing duplicates in the data is crucial to ensure accuracy in the research findings.

Data on the number of vehicles shipped the previous year was obtained and analysed in order to determine the appropriate sample size necessary to statistically represent the shipped vehicles. To convert the units of UEEE recorded to weights, the indicated average weight of the UEEE found by UNU-Keys was used (Appendix B). The UNU-Keys for EEE allow for a consistent and publicly accessible method of weight estimation, which can be replicated by future studies regardless of where those studies are based. Based on a rough assessment of the age of the UEEE prior to shipment, the weights of EEE placed on the market were estimated by weight. This data shows a further narrowing of exports likely to contain UEEE, with 90% of vehicles that contained UEEE being cars or vans. Cars and vans also contained approximately 87% of the documented UEEE by weight. This data shows a further narrowing of exports likely to contain UEEE. As found by Odeyingbo et al., (2017), Irish RoRo vehicles have been shown to contain significantly more UEEE than containers; this research identifies that within shipments of RoRo vehicles cars and vans are far more likely to contain UEEE and contain significantly more UEEE than trucks.

Additionally, vehicles falling into neither the category of trucks nor cars or vans comprised <1% of the sample and were not found to have contained UEEE. These vehicles are also discounted from the following totals and were not included in historical data provided by the shipping company. The results of data collection on the remaining 279 sampled vehicles is laid out in Table 4.1.

| Type of Vehicle | Cars/Vans | Trucks | Total |
|----------------|-----------|--------|-------|
| Vehicles Sampled | 177       | 102    | 279   |
| Weight of EEE Sampled (kg) | 4834 | 707 | 5542 |
| Average Weight of UEEE per vehicle (kg) | 27 | 7 | 17 |
| Average Weight of UEEE per vehicle containing EEE (kg) | 102 | 141 | 106 |

Of the sampled vehicles during the period of study, 29 vehicles, comprised of 27 cars or vans and 2 trucks, were found to be non-compliant by waste enforcement officers and were placed on hold. Therefore, these vehicles were not shipped at the time sampling occurred and the UEEE they contained was not included in the totals. Additionally, vehicles falling into neither the category of trucks nor cars or vans comprised <1% of the sample and were not found to have contained UEEE. These vehicles are also discounted from the following totals and were not included in historical data provided by the shipping company. The results of data collection on the remaining 279 sampled vehicles is laid out in Table 4.1.

Cars and vans represented 63% of RoRo vehicles, while trucks represented 37%. Upon inspection of these vehicles, 16.88% were found to contain some form of UEEE whereas the remainder had none, either containing other used equipment such as clothing, furniture, or car parts, or were shipped empty. Despite trucks representing roughly 1/3 of the sample size, cars and vans were more than 5 times more likely to contain UEEE, with 90% of vehicles that contained UEEE being cars or vans. Cars and vans also contained approximately 87% of the documented UEEE by weight. This data shows a further narrowing of exports likely to contain UEEE. As found by Odeyingbo et al., (2017), Irish RoRo vehicles have been shown to contain significantly more UEEE than containers; this research identifies that within shipments of RoRo vehicles cars and vans are far more likely to contain UEEE and contain significantly more UEEE than trucks.

4. Results and discussion

The following section presents the results found over the period of study. Overall, a total of 308 RoRo vehicles were sampled, representing about 35% of the number of vehicles shipped annually based on the historical data provided by the shipping company. Over the year previous to this study, between October 1st, 2018, and September 30th, 2019, the shipping company reported a total of 868 vehicles shipped, with a breakdown of 264 cars, 374 vans, and 230 trucks. When broken down into vehicle types, the study sample represents 28% of cars and vans, and 44% of trucks. The statistical significance of the sample size was based on this historical data collected from the shipping company and was largely determined by the schedule of the waste enforcement inspections and the corresponding dates of shipment, as the number of vehicles varied by the proximity of an inspection date to shipment.
lead many exporters to ship vehicles empty.

4.2. Types of UEEE

20 types of UEEE were identified in the samples based on the UNU-Keys, including mostly commonly large equipment, temperature exchange equipment, screens, small equipment, and small IT and telecommunications equipment. Of the 20 types of UEEE recorded, flat panel display televisions were the highest quantity of UEEE at 100 televisions, one third of the total figure. Refrigerators represented the single category of UEEE with the highest weight, with a total of 1346 kg recorded in the samples. Fig. 4.2 highlights the distribution. Categories with less than 50 kg each have been merged for the purpose of this figure, however, further detail for all categories can be found in Appendix B.

This study highlights the necessity for the use of an integrated categorisation of used EEE such as the UNU-Keys, that constitutes all groupings of waste electronics, not just small IT and telecommunications equipment. This stands in contrast to similar studies which suggest the bulk of shipments of UEEE shipped from developed countries to developing countries consist mostly of IT and telecommunications equipment.

Often, studies on the flows of WEEE focus mainly on the streams of televisions, monitors, and computers due to the presence of valuable metals and ease of refurbishment and reuse (Baldé et al., 2016). For this reason, this research is unique as it not only focuses on electronics and IT equipment such as laptops, desktops, mobile phones, and televisions but also encompasses all categories of WEEE. This approach is especially feasible in the examination of RoRo vehicles as each type of UEEE is travelling in the same stream. The trend observed in this research shows that had the scope been limited to the popular streams of computers and mobile phones, significant flows of UEEE could have been missed. This is often highlighted as one of the drawbacks of similar studies, along with the fact that there is no internationally agreed classification for exports of UEEE versus WEEE (Baldé et al., 2016; Odeyingbo et al., 2019). Also, the need to broaden the scope of related research is highlighted in the Global E-waste Monitor, which indicates that large electrical appliances are the second category of e-waste most generated. With increasing exports of this type of used electronics, its weight will significantly influence the volume of generated WEEE in destination developing countries.

4.3. Quality of equipment shipped

In the similar study by Odeyingbo et al., (2019), a highlighted recurrent issue surrounding transboundary shipment from developed countries is the lack of functionality tests at the countries of origin. In Irish UEEE shipments, the NTFSO requires the receipt of electrical certificates, completed and signed/stamped by an electrician or technician after testing is conducted to ascertain the functionality of equipment. Electrical certificates are only issued when the UEEE is proven to be shipped with an intent of reuse hence UEEE primarily shipped for recycling or major refurbishment works is controlled. As mentioned in Section 2.4, vehicles containing UEEE but no certificate are placed on hold by waste enforcement officers and cannot leave the port.

Also, upon inspection, it is observed that equipment is in good condition and that measures were taken to prevent damage of equipment in transit. Electronics, such as televisions, were required to be properly placed and secured to avoid damage (Fig. 4.3).

Based on the indications of stricter enforcement by shipping agents and waste enforcement officers in recent months, previously discussed in Section 4.1, the quality of UEEE is likely to have improved as non-functional WEEE and improperly packaged equipment that is likely to become WEEE on the journey. However, further investigation into the presence and accuracy of electrical certificates would be required to assess the changes in functionality since 2017 when 60% of EEE exports into Nigeria from Ireland were found to be functional and ready for reuse (Section 2.1; Odeyingbo et al.).

4.4. Economic drivers and destination

In Section 2.1, the major difference in the factors responsible for transboundary movement of UEEE were noted as push or pull factors. Findings from this research identifies pull factors guiding the export of UEEE in RoRo vehicles from Ireland. Traders of used vehicles play a significant role as UEEE is loaded into used vehicles and frequently shipped to exporter’s hometowns, in this case mostly in West Africa. A key reason for this is likely the fact that vehicles shipped are priced by dimensions not weight, this means that whatever is contained in the vehicle, no matter the weight, will not attract any additional fee.

94% of the total vehicles shipped in the previous year were shipped to Lagos, which serves as a major import hub of used electronics due to an increasing demand in the destination country. This also reflects the breakdown of African immigration to Ireland. The initiators of these exports are largely Nigerians, who use the opportunity of shipping used vehicles to include UEEE for personal use or resale.
4.5. Value of used electronics

As discussed in Section 2.1, the demand for used electronics in Nigeria is a growing development. The availability of UEEE affords people of lower economic means to improve their standards of living. For example, some of the EEE observed include essential modern conveniences, such as refrigerators to elongate the lifespan of foods, considering the humid weather akin to tropical regions like Nigeria, and IT equipment, which allows for internet access. By having a cheaper option, people can more readily afford electronics to improve their social status and quality of life. Additionally, with factors such as job creation and income from preparation for reuse, as highlighted in Section 2.1, these products improve the standard of living of affected individuals in developing countries. Data collected on the value of exported UEEE indicates that the products this research has shown to be frequently exported, such as used TVs, refrigerators, and washing machines, had a strong correlation with the demand and ready market for these items in Nigeria. The unit quantities and weight of used electronics favour this trend as seen from the distribution in Fig. 4.2, refrigerators, televisions, freezers, washing machines, and cookers dominate UEEE exported from Ireland to Nigeria. On this basis, the market for these items was examined and the associated values on the Nigerian resale market were determined, illustrated in Table 4.5.

Prices differ with manufacturer, model, size, and second-hand value. A comparison of the obtainable value in Ireland and in Nigeria show that these used electronics hold the potential promise of profit from resale. The total value of sampled UEEE, amounting to €47,112, can be adjusted based on the historical number of shipped vehicles to an annual value of €147,225. These values show that the listed asking prices on the online Nigerian reuse markets trend higher than the average values at origin declared on shipment packing lists. Some of these differences may result from poor estimations of value placed on the packing lists by the exporter. However, the large and consistent differences illustrate the high demand for used products in the destination market, and the financial incentive for exporters to place these products for sale on Nigerian markets rather than Irish ones. This is particularly true due to the low cost of shipping UEEE, as the price for shipment is based only on the vehicle and not on the contents of said vehicle. Therefore, the only cost associated with shipping vehicle contents is obtaining certificates of functionality.

| UEEE Type    | Average value as declared on shipment (€) | Average value as declared on shipment (₦) | Used Market Price Nigeria (£) | Used Market Price Nigeria (₦) |
|--------------|-------------------------------------------|------------------------------------------|------------------------------|-------------------------------|
| Television   | 112 - 131                                  | 45,000 - 52,915                          | 242 - 372                    | 97,500 - 150,000              |
| Washing Machine | 124 - 326                                  | 50,000 - 131,271                        | 199 - 273                   | 80,000 - 110,000             |
| Fridge       | 50 - 76                                    | 20,000 - 36,005                          | 118 - 186                   | 47,500 - 75,000              |
| Freezer      | 87 – 184                                   | 35,000 – 74,178                         | 100 – 112                   | 40,000 - 45,000              |
| Cooker       | 112 - 165                                  | 45,000 - 66,442                          | 131 - 149                   | 52,500 - 60,000              |

Note: 402 NGN = 1 Euro.

Fig. 4.3. Improperly packaged UEEE placed on hold by waste enforcement officers (Dublin City Council 2019).

5. Conclusion

This study presents the first comprehensive estimation of UEEE shipments exported from Ireland in roll-on roll-off vehicles conducted at the port of origin. The data presents a unique expansion of insight into the shipment channel from Ireland to West Africa and suggests a stark change in export behaviour in the years between the 2017 Person in the Port report and the period of study ending in March 2020. Per Section 4.1, while 60% of RoRo vehicles exported from Ireland and entering the port in Lagos were found to contain UEEE in 2017, less than 20% of vehicles leaving Ireland contained UEEE in this 2020 study. This change in behaviour is speculated to source from increasingly stricter regulatory requirements over the past several years. These findings present a number of opportunities for further research into the stark behavioural changes observed as well as in subjects regarding unidentified pathways of UEEE and WEEE export.

Further results illustrate that the potential value of UEEE on the resale market in Nigeria continues to drive demand for import, with exported UEEE estimated to value nearly €150,000. With low costs for certifying functionality with electrical certificates and no added cost for shipping vehicle contents, this economic value in Nigeria, where used goods are in higher demand than in Ireland, is a significant driver of export. An opportunity for further research exists in an examination of the process, cost, and verification of electrical certificates. Additionally, surveys of the perspective and behaviour of the exporters and owners of the RoRo vehicles would also provide valuable insight in future studies.

The methods developed and employed in this study allow for future estimation of UEEE exports in Ireland based on number of vehicles and vehicle types in a particular shipment or over a period of time. Additionally, the straightforward methods are expandable across EU and global shipments to provide better understandings of UEEE flows, data for which is currently limited in existing literature. This is of significant value to all stakeholders concerned with the regulation, enforcement, and safety of UEEE shipment. Notably, the results of this study and further studies using these methods also contribute valuable statistics for the calculation of WEEE collection targets, which may adjust based on high or low quantities of EEE exported and therefore no longer available for collection.
Credit author statement

Kathleen McMahon: Conceptualization, Methodology, Formal Analysis, Investigation, Writing – Original Draft, Writing– Review and Editing, Visualization; Chidinma Uchendu: Resources, Investigation, Writing – Original Draft; Colin Fitzpatrick: Conceptualization, Methodology, Writing – Review and Editing, Supervision

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Conflicting Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Relevant Compliance Documentation

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**Electrical Declaration**

**Electrical Contractor** (Name & Address):  
Customer Name & Address:  
Contact Details:  
Email:  
Safe Electric Registration No:  

| Make: | Model: |
|-------|-------|
| Serial Number: | Year of Production: (if known) |
| Detail Method of Testing: | |

Result of test: Pass or Fail: 

Date of Test: 

Estimated value of item: € 

Name and address of testing location: 

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**Declaration of Functionality:**

I declare that the electronic/electrical item specified above is in working condition and is suitable for re-use for its original purpose and meets all European Safety Standards.

Signed: Company Stamp: 

Date: 

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1 Electrical Contractor: Must be a registered electrical contractor with the Register of Electrical Contractors of Ireland (REC) in accordance with the Electricity Regulation Act 1999, as amended.

*Please note that ozone depleting substances are a prohibited export from the EU.

*Please be aware that providing false/misleading information to an authorised officer is an offence under the Waste Management Act 1996, as amended, and the Waste Management (Shipment of Waste) Regulations 2007.

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# Packing List

| Liabie person/Sender (Name & Address): | Sender’s Agent/Freight Forwarder (Name & Address): |
|---------------------------------------|---------------------------------------------------|
|                                        |                                                   |
| Phone No:                             | Phone No:                                         |
| Fax:                                  | Fax:                                              |
| Email:                                | Email:                                            |

Consignee (Name, address, contact details):

Name and address of loading location:

Additional Notes:

| Item Description: make/model etc | Serial Number | Qty | Estimated value | Invoice present Y/N? |
|----------------------------------|---------------|-----|-----------------|---------------------|
|                                  |               |     |                 |                     |
|                                  |               |     |                 |                     |
|                                  |               |     |                 |                     |
|                                  |               |     |                 |                     |
|                                  |               |     |                 |                     |
|                                  |               |     |                 |                     |
|                                  |               |     |                 |                     |
|                                  |               |     |                 |                     |

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Appendix B. Collated Sampling Data

| UNU-Key | Description          | Quantity | Total Sampled Weight (kg) | Sum of Values (€) | Scaled Weight Estimates (kg) | Scaled Value Estimates (€) |
|---------|----------------------|----------|---------------------------|------------------|------------------------------|----------------------------|
| 0103    | Kitchen              | 17       | 810                       | 2244             | 2531                         | 7013                       |
| 0104    | Washing Machines     | 13       | 943                       | 2577             | 2947                         | 8053                       |
| 0108    | Fridges              | 33       | 1346                      | 3152             | 4206                         | 9850                       |
| 0109    | Freezers             | 10       | 441                       | 1325             | 1378                         | 4141                       |
| 0114    | Microwaves           | 21       | 481                       | 1134             | 1503                         | 3544                       |
| 0201    | Other Small Household| 9        | 9                         | 1824             | 28                           | 5700                       |
| 0202    | Food                 | 10       | 33                        | 445              | 103                          | 1391                       |
| 0203    | Hot Water            | 2        | 4                         | 88               | 13                           | 275                        |
| 0302    | Desktop PCs          | 9        | 79                        | 1437             | 247                          | 4491                       |
| 0303    | Laptops              | 2        | 3                         | 274              | 9                            | 856                        |
| 0304    | Printers             | 17       | 175                       | 1144             | 547                          | 3575                       |
| 0307    | Professional IT       | 2        | 80                        | 569              | 250                          | 1778                       |
| 0403    | Music Instruments, Radio | 11 | 41                        | 2147             | 128                          | 6799                       |
| 0404    | Video                | 3        | 11                        | 486              | 34                           | 1519                       |

Estimated Total Value of shipment (Euros): €

Declaration of liable person:
- I declare that the items within this shipment have been packed individually with appropriate protection against damage during transportation, loading and unloading and in such a manner so as not to cause environmental risk.
- I declare that all of the electronic and electrical equipment within this shipment are re-useable in their current condition and are not waste as defined by Article 3(1) of Directive 2008/98/EC.
- I declare that all items of electronic and electrical equipment within this shipment have been tested and that the result of the functionality test has been attached on the outer packaging of each item.
- I declare that all vehicles in this shipment are re-useable in their current condition or in need of only minor repair.
- I declare that all used vehicle parts within this shipment are fit for direct re-use or require only minor repair and do not contain any hazardous components/substances.
- I declare that I am the legal owner of the items within this shipment, all of which are for direct re-use in their current condition.

Signature: __________________________
Block Capitals: __________________________
Date: __________________________

* Please note that ozone depleting substances are a prohibited export from the EU.

*Please be aware that providing false/misleading information to an authorised officer is an offence under the Waste Management Act 1998 as amended, and the Waste Management (Shipments of Waste) Regulations 2007

*Please be aware that any shipment that requires further investigation or is required to be returned to origin may incur a Return to Origin Fee of £700.

*Please be advised that any shipment that requires a written direction to be issued by this office may incur a Monitoring Fee of £30.

*Please be advised that the shipment of waste in contravention of Regulation (EC) 1013/2008 may result in a court appearance and if convicted fines can be issued up to £5,000 per offence and/or costs and/or 12 months imprisonment.

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