Estimating job creation potential of compliant WEEE pre-treatment in Ireland

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ABSTRACT

While significant focus has been placed on the environmental and health impacts of waste electrical and electronic equipment (WEEE) treatment, a gap exists with respect to job creation in WEEE treatment. The creation of employment opportunities, and especially of decent work, is an important factor in the growing green and circular economies. This research investigates potential job creation in the Irish WEEE pre-treatment sector by examining the labour requirements at a certified e-recycling facility which conducts all necessary pre-treatment processes, as detailed in the WEEE Directive, and is currently treating 75% of Ireland’s WEEE. The study developed and executed a method of estimating the mass of WEEE associated with full-time job equivalencies per category treated. Through observation and measurement of the methods and time required for each of the pre-treatment steps and using categorisations of WEEE established by United Nations University to assign weights per category treated. Through observation and measurement of the methods and time required for each of the pre-treatment steps and using categorisations of WEEE established by United Nations University to assign weights per unit, it was determined that between 338 and 1,967 tonnes were required to equate with one full-time job for the categories large household appliances (LHA), CRT/LCD/LED screens, microwave ovens, and mixed waste. Subsequently, the results were applied in order to estimate the foregone jobs due to untreated WEEE arising in scrap metal collections. It was found that diversion of this waste to a WEEE pre-treatment facility would result in the creation of more than 12 jobs. This research opens doors to further investigate job creation across European Union (EU) member states and globally using the straightforward and consistently applicable and adaptable methods developed here.

1. Introduction

Increasing demand for electronic products globally has resulted in a significant increase in the associated waste electrical and electronic equipment (WEEE), presenting a number of issues for consideration (Parajuly 2019). Classified as a hazardous waste due to a composition of numerous toxic elements, WEEE poses a threat to both environmental and human health when disposed of or treated without care (European Commission, 2019; Oguchi et al., 2013). Manufactured using numerous valuable and critical raw materials (CRMs), which must be initially obtained through mining with only a fraction making it through value recovery in recycling, electrical and electronic equipment (EEE) presents economic and social issues at the beginning and end of the product life cycle (Pini et al., 2019). These concerns regarding environmental, social, and economic effects of WEEE have resulted in a global legislative focus on regulating all aspects of WEEE treatment.

The European WEEE Directive provides the regulatory environment for WEEE collection and treatment in the European Union (EU). Compliant WEEE treatment involves a high degree of attention to health and safety conditions, separation of materials, and selective treatments in order to reach the stipulated recycling targets. This essential pre-treatment processing is mostly performed manually (Bigum et al. 2012; Chancerel et al. 2009; Johansson and Björklund 2010). These requirements add additional steps to the treatment processes compared to traditional scrap metal recycling, which in turn results in a higher number of labour hours. Additionally, costs for compliance standards certification, proper reporting, administration, equipment, and technology rise for compliant facilities in stricter regulatory environments, while complimentary channels do not absorb these additional costs and therefore have a distinct economic advantage through limited or a lack of reporting, a lack of required specified treatments (Magalini and Huismann 2018). In addition, complimentary channels, through non-segregation of WEEE and materials shredding, are relatively ineffective at precious metal recovery (Chancerel et al., 2009; Johansson and Björklund, 2010) and are not providing optimal opportunity for CRM recovery (Ueberschaar et al., 2017).

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While there has been increasing interest in research relating to WEEE treatment, a review of related literature has indicated that over the last two decades a significant gap, discussed in detail in Section 2.1, in research estimating the number of jobs created through compliant treatment is evident, particularly in the collection of primary data at working facilities such as that observed in this research. This provides an opportunity for research to produce insight by estimating the employment consequence of foregone jobs in compliant WEEE recycling due to e-waste arising in non-compliant or informal WEEE treatment. This study develops and tests a methodology based on an adaptation of Methods Time Measurement (MTM) to estimate the labour hours, and therefore jobs, required in the pre-treatment of WEEE in Ireland, based on observations of a certified e-recycling facility where 75% of WEEE collected in Ireland is treated. Although there is further potential for estimating jobs foregone in relation to collection and end processing (Fig. 1), the scope of this study is focused on labour specifically involved in the pre-treatment of WEEE.

The estimated labour required to treat WEEE is combined with the results from a separate study quantifying the amount of untreated WEEE in Ireland found in non-compliant channels, specifically, scrap metal collections. The following sections will outline the relevant academic literature, a time study conducted at a WEEE treatment facility in Ireland, the resulting labour requirements for pre-treatment of different categories of WEEE, and the application of the labour time results to the amount of WEEE arising in non-compliant processes.

2. Background

2.1. Job creation in WEEE treatment

As focus on the importance of moving toward a green economy, defined by the United Nations (UN) as an economy with low carbon emissions, high resource efficiency, and high social inclusivity, has become of growing global interest, the question of employment in this new economy has emerged as a frequent topic of discussion. Green jobs have been suggested to have the potential to contribute greatly to future job growth, with the green economy estimated to create more than 20 million jobs, greatly exceeding the estimated job losses stemming from decreases in high pollution activities such as mining (ILO 2018). Many of these jobs are attributed to the greening of the energy sector, however, job creation in the treatment and reuse of waste electrical and electronic equipment has been less explored, as will be discussed throughout this section.

Efficient recycling resulting in high resource recovery and low environmental impact, particularly in developing countries, has been suggested to involve a high degree of manual rather than mechanical dismantling. Wang et al. (2012) describe the ‘best-of-two-worlds’ philosophy in which best practice pre-processing in developing countries is combined with highly technical and innovative end-processing in developed countries results in better economic and environmental performance where state of the art end-processing facilities have not yet been built. The results found by Wang and colleagues point to a degree of labour involved in the pre-processing of WEEE and also illustrates a common thread of interest found in academic literature on WEEE treatment, namely, a heavier focus on solutions for developing nations and emerging economies.

An area of particular focus in research relating to jobs in ‘green’ sectors, and specifically in WEEE treatment, is the creation of decent work, which encompasses employment creation, social protections, rights at work, social dialogue, and more, and is called for in Goal 8 of the United Nations’ Sustainable Development Goals. Recently, a review by the International Labour Organization (ILO) (2019) examined existing sources of information regarding in the treatment of WEEE, resulting in a valuable pool of estimates and analyses to provide a comprehensive view of the challenges in documenting the creation of decent work in WEEE treatment. The review consolidates available national estimates, acknowledging that the process of producing the estimates was at times unclear (Table 2.1).

The ILO review also identified several weight based estimates, the first of which equates 1,000 tonnes of WEEE with 40 jobs in collection and sorting in the United Kingdom (UK) (Friends of the Earth 2010), and another equates 15 jobs in sorting and recycling of WEEE with an additional 30 in landfills and 200 in repair (Sampson 2015). Relational estimates were also presented in the ILO’s analysis, estimating that 1 tonne of WEEE could support 1 job in Kenya (Guilcher and Hieronymi 2013), and that recycling electronics had the potential to support 10 times more jobs than landfilling approximately two decades prior to this study (MassDEP 2000). In addition to the national estimates reviewed by the International Labour Organization, a 2017 study by Lydall et. al mapping the WEEE treatment landscape in South Africa collected data through surveying and conducting face-to-face interviews with 27 companies involved in dismantling, pre-processing, and processing of WEEE.

Table 2.1
Available national and municipal estimates of employment across WEEE treatment sectors (ILO 2019; [1] Wang et al. 2013; [2] ILO 2014; [3] ILO forthcoming; [4] Ogungbuyi et al. 2012; [5] eWASA 2014; [6] Lepawski and Billah 2011).

| Country/ Municipality | Estimated # of workers | Description of work category | Ref. |
|------------------------|------------------------|------------------------------|------|
| China                  | 690,000                | Collectors or recyclers      | [1]  |
| Serbia                 | 5,000-8,000            | Collectors                   | [2]  |
| Argentina              | 34,000                 | In the e-waste value chain   | [3]  |
| Nigeria                | 100,000                | In the e-waste economy       | [4]  |
| South Africa           | 5,324 in 62 companies  | eWaste Association of South  | [5]  |
| Dhaka, Bangladesh      | 60,000                 | In e-waste                   | [6]  |
| New Delhi, India       | 10,000-25,000          | Informal e-waste workers     | [7]  |

1. https://www.unenvironment.org/regions/asia-and-pacific/regional-initiatives/supporting-resource-efficiency/green-economy

2. https://www.iло.org/global/topics/decent-work/lang-en/index.htm
South African WEEE. Based on survey and interview results indicating the number of employees and amount of WEEE treated by each firm, the study estimated that 1000t of WEEE handled represented 25 jobs. The study describes the WEEE recycling sector as a not yet significant employer, however, acknowledges the potential for increased employment with increased WEEE entering treatment.

A number of variables differ across each of the aforementioned estimates; in addition to the difference in weight based, worker counts, or relational estimates, some represent different sectors, branches of the same sector, regulatory environments, working conditions, average working hours/annual full-time job definitions, and even time frames. Thus, while several estimates are available in the literature, few are comparable to an extent allowing replication across multiple regions, governments, economic conditions, etc. There is significant value in closing this gap through developing a globally expandable method establishing the potential of more formalised WEEE treatment to create decent work opportunities. Furthermore, despite concerns that a shift to a green economy may result in a potential eventual decrease in employment sourced from raw material extraction and manufacturing, job creation in the WEEE sector may fill an increasing need for employment opportunities in reprocessing, services, and waste management to address a growing rate of WEEE generation (ILO 2019).

Examination of the aforementioned review as well as an extensive review of academic literature for the purpose of this study has indicated that specific estimation of job creation and labour hours required in the treatment, and especially in the pre-treatment, of WEEE has little further presence in recent academic literature, with few notable exceptions examined in the following subsection, 2.1.1. While much literature focuses on the environmental and health impacts of WEEE treatment in developing countries, few mention the number of workers. Of those papers where numbers are mentioned, estimates were largely found not to have been heavily evidence-based and tended towards loose estimates.

For example, it is often cited that 100,000 workers, or around 80% of families, are employed in the e-waste economy in the town of Guiyu, China, known as one of the largest e-waste sites in the world (Heacock 2015; Lundgren 2012; Wong et al. 2007). However, despite a high prevalence of mentions in papers describing health impacts of informal WEEE treatment in Guiyu, such as adverse birth outcomes (Kim et al. 2020) and levels of lead in the blood of children (Huo et al. 2007), the original source of this number is difficult to identify. As this number is used for contextualizing impacts in literature describing research on the environment, economy, and society as all three ‘pillars’ of sustainability (Jørgensen 2008), and allows for impacts on indicators such as human capital, human well-being, work conditions, human rights, cultural heritage, socio-economic factors, and social behaviour, although there is not a specified set of recommended indicators (Weidema 2006; Benoît et al. 2010). Social life cycle assessment (S-LCA) has included examination of job creation and has been applied in studies of the WEEE sector.

Two particular studies used S-LCA to estimate job creation in the treatment of WEEE under different circumstances. Pini et al. 2019 uses S-LCA to compare entire life cycles of new WEEE and WEEE that has been ‘prepared for re-use,’ a term used in EU contexts to refer to the processes by which products or components that have been classified as waste are re-used (Directive 2012/19/EU). The authors examined economic, environmental, and social indicators over several scenarios in an Italian context, introducing job creation as “number of employees” as a new social category in the analysis. The S-LCA determined that the preparation for reuse of WEEE created new opportunities for employment and business in areas such as maintenance, repair, and upgrade, finding increases in job creation in most situations under studied scenarios for preparation for re-use.

A 2010 study by Prakash et al. also used S-LCA to examine the socio-economic state of the informal e-waste sector at the Agbogbloshie scrap yard and the broader community in Accra, Ghana, and to explore the potential for international recycling cooperation with said informal sector. The study assessed socio-economic impacts for workers, local communities, and society as three main stakeholder categories, with a number of different indicators per group (Table 2.1.1).

Employment creation falls into the societal impacts category. Through in-depth interviews and visual inspections using an ‘S-LCA assessment sheet’ the study found several ranges of estimates of job creation in Ghana’s e-waste sector: 4,500-6,000 collectors or recyclers in the study yard and the broader community in Accra, Ghana, and to explore the potential for international recycling cooperation with said informal sector. The study assessed socio-economic impacts for workers, local communities, and society as three main stakeholder categories, with a number of different indicators per group (Table 2.1.1).

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Additionally, many of these estimates were based on regulatory and economic situations differing greatly from country to country and spanned decades in terms of estimation. This, as well as difficulty in defining WEEE or e-waste across regions and governmental bodies presents additional challenges in estimating employment potential in WEEE treatment globally (ILO 2019). The preceding contents of this section expose the gap in academic literature regarding estimations, particularly those based on primary data collection, of jobs created through compliant pre-treatment of WEEE in European countries where regulations, safety standards and employment laws must be adhered to. This original research described in this paper addresses that gap through primary data collection and analysis of the labour inputs in pre-treatment of Irish WEEE.

### Table 2.1.1

| Stakeholder Categories | Workers | Local Communities | Society |
|------------------------|---------|------------------|--------|
| **Socio-economic indicators** | **Safe & healthy working conditions** | **Safe & healthy working conditions** | **Unjustifiable risks** |
| Freedom of association and right to collective bargaining | | | |
| Equality of opportunity and treatment and fair interaction | | | |
| Forced labour | | | |
| Child labour | | | |
| Remuneration | | | |
| Working hours | | | |
| Employment security | | | |
| Social security | | | |
| Professional development | | | |
| Job satisfaction | | | |
| | | | |
| **Employment** | **Community engagement** | **Socioeconomic opportunities** | **Contribution to national economy** |
| | | | **Contribution to national budget** |
| | | | **Impacts on conflicts** |
numbers result in a total of 20,300-33,600 of people employed by collection, recycling, and refurbishing of e-waste in Ghana in 2010, and that up to 57,600 more people depend on collection and recycling activities, and up to 144,000 depend on refurbishment activities in that year. This study represents the most comprehensive estimation of regional impacts of e-waste on job creation and also shows the significant contribution these jobs make with the high number of people employed in or dependent on e-waste treatment.

While the methods associated with S-LCA have not been specifically adopted in the same manners for the purposes of this study, discussion of S-LCA illustrates the importance of employment, especially, decent work in e-waste research and where the results found in this study contribute.

2.1.2. Methods time measurement

It is often necessary in engineering and processes such as manufacturing, to measure the amount of time elapsed for the completion of a repetitive task. This is frequently done in order to identify steps in a process where the required time can be reduced in order to increase efficiency, or in the case of EEE, to maximise the efficiency for disassembly from the design stage as a part of eco-design. Designing a product with efficient disassembly in mind presents a challenge requiring an evidenced set of time data from which the designer can make decisions on efficiency, as suggested by Yadav et al. (2018) in their research on product recyclability. One standard methodology used to measure, record, and analyse these times is Methods Time Measurement (MTM). MTM builds and utilises a set of pre-determined times required to complete a task, in relation to this paper, the manual dismantling of electronics.

In the 1970s, the Maynard operation sequence technique (MOST) was developed as an adaptation of MTM in which research is conducted on a sequence of motions that a worker dismantling a product makes, and the time associated with each motion. Recently, research by Vanegas et al. (2018) used MOST to develop and propose an ease of Disassembly Method (eDiM) to calculate disassembly time of a product based on a given sequence of actions and product information. Using liquid crystal display (LCD) televisions as a case study, Vanegas et al. utilise the developed eDiM to evaluate the influence of improvements in the design of LCD products, demonstrating the potential for eDiM to support the circular economy through use in the development of standards and legislative tools for the eco-design of EEE.

MRM provides an established and well-tested methodology to measure the labour requirements of WEEE pre-treatment, and has not yet been used for this purpose.

2.2. Compliant treatment of WEEE

European treatment requirements are laid out within the WEEE Directive, and in the transposed version, Statutory Instrument (S.I.) 149, for Ireland. Compliant WEEE treatment facilities in Ireland are required to enact measures ensuring the safety of workers, proper disposal, improved value recovery, and minimization of pollution risks, which non-compliant pathways may or may not apply to their operations. Types of WEEE equipment, previously separated into ten categories, are now merged into six categories (Table 2.2) in the legislation as of 2018 (Directive 2012/19/EU).

These six categories define no fewer than 15 required pre-treatments including, at minimum, a removal of all fluids and a heavy focus on depollution to reduce environmental impacts of hazardous materials. For the purposes of this study, and in relation to the actual flows of Irish WEEE (discussed in the following Sections 3.1 and 4), WEEE has been separated into a different six categories: mixed waste, batteries, large household appliances (LHA), screens, separated into cathode ray tube (CRT) and liquid crystal display (LCD)/light emitting diode (LED), microwave ovens, and cooling. Each of these categories require a number of the legislatively mandated and potentially labour intensive pre-treatments. For instance, the removal of cables, batteries, large printed circuit boards, and capacitors in line with the WEEE Directive is common across all six categories, as is the required removal of hazardous substances, such as plastics containing brominated flame retardants. Screens and cooling equipment require additional pre-treatment to remove fluorescent coating from CRT components, mercury from LCDs, and the ozone depleting gases chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), and hydrocarbons (HC) from temperature exchange equipment such as refrigerators and freezers (Directive 2012/19/EU).

In addition to the required pre-treatments, WEEE collection is also subject to requirements relating to the reporting of quantities in order to meet set collection targets. From 2019, targets mandated within the WEEE Directive and transposed member state legislation are set at collection of 65% of the average equipment placed on the market averaged over the previous three years, or 85% of WEEE generated, along with set targets for recovery and recycling/preparation for reuse based on the new 6 categories of WEEE (Table 2.2b) (Directive 2012/19/EU).

Often, organisations acting as “compliance schemes” are established to organise collection and treatment on behalf of producers. Quantities of WEEE treated must be reported to compliance schemes by weight and category, thus requiring the weighing of equipment and separation processes in place at treatment facilities (Directive 2012/19/EU). The Directive stipulates requirements on the marking of waste, measure to ensure the health and safety of workers, as well as permitting member states to set up minimum quality standards. Standards vary by member state and cover areas such as health and safety and treatment quality. Notably, Ireland has one of only a few European facilities to achieve compliance with the WEELABEX standard, joined by only France and the Czech Republic in use of this standard in Europe. The development of the WEELABEX standard has subsequently contributed to the devel-

Table 2.2b
Recovery and recycling/preparation for reuse targets as of 15 August 2018 (Directive 2012/19/EU, Annex V).

|                | Recovery | Recycling/preparing for reuse |
|----------------|----------|------------------------------|
| 1  Temperature exchange equipment         | 85       | 80                           |
| 2 Screens, monitors, and equipment         | 80       | 70                           |
| containing screens having a surface greater |          |                              |
| than 100 cm²                               |          |                              |
| 3 Lamps                                    | n.a.     | 80                           |
| 4 Large equipment (any external dimension  | 85       | 80                           |
| more than 50 cm)                           |          |                              |
| 5 Small equipment (no external dimensions  | 75       | 55                           |
| more than 50 cm)                           |          |                              |
| 6 Small IT and telecommunications equipment | 75       | 55                           |
| (no external dimension more than 50 cm)    |          |                              |

http://ec.europa.eu/environment/waste/weee/pdf/faq.pdf
ompliance of EN Standards 50614 and 50625, which document the minimum quality standard for collection, transport, reuse, and treatment of WEEE. Other common standards include those such as the British Quality PAS114, which is currently in use in Ireland to standardise the process in which WEEE is treated.

The report WEEE Recycling Economics (Magalini and Huisman, 2018) illustrates the financial cost of compliance including meeting technical requirements and additional costs in preparations for auditing, reporting, and other related administration. Auditing and reporting alone were found to result in a cost of €4-8 per tonne and €37-42 per tonne, respectively (Magalini and Huisman 2018). Overall, the avoidance of these regulatory requirements could result in a decrease in 20% of costs related to reporting and auditing and 50-60% of costs relating to depollution and disposal (Magalini and Huisman 2018).

Processing of WEEE in scrap yards can be best described by its lack of pre-treatments. Processing of e-waste on such sites does not include the careful separation, manual dismantling, or depollution as WEEE and other hazardous waste categories are not the intended waste categories, and in fact in their untreated state are not permitted as intake, unless they are to be treated appropriately onsite. Concealed WEEE ends up at scrap metal sites as part of mixed metal loads, mostly coming from construction and demolition works and home or business clear-outs. WEEE are composites of various materials, mainly metals and plastics and are aggregated with other composite materials for shredding both in Ireland and overseas.

According to the Huisman et al. (2015) in the Countering WEEE Illegal Trade Summary Report only 35% of European WEEE disposed of over the year 2012 was treated within legally compliant waste treatment streams, as reported in official documentation for collection and recycling. Thus, the remaining 65%, or 6.15 million tons of WEEE, was found to have been exported (16%), remained in Europe but recycled in non-compliant facilities (33%), scavenged to remove valuable components (8%), or improperly disposed of in household or other waste bins (8%). Globally, by 2019, 53.6 million tonnes of e-waste was generated, but waste recycled through appropriate channels amounted to only 17% of this number, despite 71% of the world’s population living under e-waste legislation (Forti et al., 2020).

In addition to the environmental costs of improperly handled scavenged material, it is estimated that the WEEE diverted from the compliant channels of treatment amounted to 152,000 tonnes of material at a value of more than €150 million in 2018 (Magalini and Stillhart 2019). When compared with non-compliant channels of WEEE collection and treatment, compliance with the legislative requirements and those within standards likely results not only in the loss of economic competitiveness and opportunity for compliant facilities, but also in job creation for the WEEE treatment sector.

Ireland’s waste collection and treatment has in recent years reached collections targets stipulated by the WEEE Directive through collections from civic amenity sites, retailer takeback schemes, and special collection events. Ireland has previously met WEEE collection targets, reaching 51% collection in 2017, exceeding the 45% target of the time (EPA 2019). However, the increased collection target of 65%, 14% above the rate of collection in 2017, will prove a challenge for the Irish WEEE system. Research by Ryan-Fogarty et al. (2020a) illustrates the quantity of WEEE arising in “complementary” channels, such as metal scrap yards. Clearly, there is a higher potential for collection of WEEE through the recapture of WEEE that is not arising in the compliant system due to disposal of hazardous waste in collections, scrap metal collections, and both illegal and legal export (Ryan-Fogarty et al. 2020b). Additionally, lifetime extension through second-hand sales, refurbishment, remanufacture, as well as long term storage result in a delay in EEE arising in the compliant waste stream and facilities (Ryan-Fogarty et al. 2020b). Quantifying WEEE not arising in compliant recycling systems, and estimating the economic and social potential through job creation can contribute to enacting measures to channel WEEE into e-recycling facilities.

3. Methods

3.1. Methods overview

This study employs mixed methods to present a case study detailing WEEE recycling and pre-treatment in the Irish sector. The objective of this study is to estimate job creation per amount of WEEE types under conditions compliant with EU regulations, and subsequently to apply this potential to the amount of WEEE found at noncompliant facilities. Ireland has strict laws and controls on work conditions, particularly regarding health and safety and minimum wage plus entitlements for employees.

The facility, one of only two in the Republic of Ireland and treating a majority of the country’s WEEE and described in detail in Section 3.2, voluntarily participated, providing privileged access to researchers to observe and record the dismantling of WEEE carried out on site. In order to assign evidences values to the labour input hours for each stream of WEEE at the facility, and therefore estimate job creation, data collection was conducted through direct measurement time study observations at a certified compliant WEEE facility in Ireland. This data was analysed quantitively and through the use of flow map diagrams.

Finally, data collected on WEEE that is discarded in scrap metal collections without appropriate treatment is used to forecast job creation potential in this sector if segregated WEEE collection rates increase. This provides a preliminary basis for policy makers and producer responsibility organisations to apply their own cost-benefit scenarios to increase WEEE collection. The following sections provide more detailed descriptions of methods employed at each stage of this study.

3.2. Site description

The facility where the study was conducted treats 75% of the WEEE collected through compliance schemes in Ireland, consisting of two sites, treating six main types of WEEE, which are outlined in Fig. 3.3. WEEE is already largely segregated when it arrives into the facility, as waste segregation is highly promoted at public collections to allow for efficiency in pre-treatment. However, smaller quantities of temperature exchange equipment, LHA, microwave ovens, and screens are also separated from mixed waste which also arrives on site. Additionally, products containing batteries are temporarily diverted from the mixed waste stream and returned following battery removal, in line with legislation and fire safety precautions.

As the facility is within Ireland, it is subject to the strict regulatory environment described in the Section 2.2 of this paper, compliant with the WEEE Directive and S.I. 149. The facility also exists in a competitive economic environment.

3.3. Time study data collection

Time studies use observation and measurement, to determine the amount of time required to complete a particular task under particular conditions. Specifically, this study uses a form of Methods-Time Measurement (MTM), in which recorded observations of the method by which a task is completed and the amount of time elapsed during that the completion of that task. In the case of this study, the methods of pre-treatment for recycling specific streams of WEEE (described in Sections 3.3 and 4) were recorded, e.g., the specific steps of dismantling and preparing a large household appliance for end processing, and from the recording of those methods the time required to complete each task, e.g., removing a component, sorting, compacting, was determined. The methods have been uniquely adapted for the purposes of this study as, in contrast to those by Vanegas et al. (2018) and Yadav et al. (2018), previously mentioned in Section 2.1.2, this study is focused solely on the labour requirement of a treatment process of existing WEEE in relation to job creation rather than how changes in design may affect the ease of disassembly or recyclability.
Sampling consisted of observations of treatment operators dismantling WEEE, identifying distinct steps in the dismantling process, and recording the time required for each step either by unit of equipment or batch of items. Observations were conducted on six main processes (Fig. 3.3) based on how each type of WEEE was processed for pretreatment. Therefore, different types of WEEE, e.g., dishwashers and clothes dryers, that were treated by the same process in the same material flow were grouped together into one category.

Sampling was conducted over a period of three days, during which the data collecting researcher directly observed each process and recorded the time, through direct measurement, from start of process to completion using a stop watch. Measurements were recorded for each worker to account for differences in skill and experience. The time elapsed over the duration of the treatment step was measured from the point of first contact, whether by hand or most often by forklift, where the unit or units of WEEE were unloaded from the transport vehicle to the last point of contact where they were reloaded back onto a vehicle for transport to end processing.

3.4. Data analysis

Processes were then mapped into treatment flows and each step in the treatment flow was labelled with the amount of time in minutes required for that step. The steps were then summed to result in the total labour time required for a complete process. Although short breaks and time spent cleaning up workspaces were not separated into individual steps, they were to a reasonable extent represented in the recorded times.

Weights per unit of equipment were assigned based United Nations University (UNU) Keys for WEEE classification Forti et al. (2018). Use of the UNU Keys allowed for a consistent and transparent method for assigning weights. These weights were used in both the analyses of FTE jobs per weight of WEEE at the studied facility and of potential job creation from diverting WEEE noncompliant treatment facilities.

The hours required per mass of WEEE were used to estimate the amount of WEEE associated with one full-time job in the treatment of that WEEE. An Irish full-time job is assumed herein to consist of 1,810 hours based on research by Eurofound (2017) averaging working hours, paid leave, and holidays across Irish business sectors.

Straightforward calculations were developed to determine total labour hours required to treat specific WEEE flows, whereby the amount of labour hours needed to treat a specified mass of WEEE (e.g., 100 kg/1 tonne/etc.), determined through data collection, is multiplied by the amount of WEEE that needs to be treated, resulting in the total labour hours required (Fig. 3a). Conversely, in order to determine the amount of WEEE required to fulfil the labour hours of 1 annual full-time job, these figures were simply reversed (Fig. 3b).

3.5. Application of time study findings to estimate employment potential

The associated calculations were then applied to data quantifying WEEE in Ireland moving through non-compliant pathways (Ryan-Fogarty et al. 2020a) in order to estimate the number of full-time jobs that would be required, were this WEEE diverted into pre-treatment at compliant facilities. The data used in the analysis is based on untreated WEEE arising in metal scrap in Ireland. Sample selection was made on the basis of European Waste Catalogue List of Waste Codes, scrap metal identified as 17 04 05\(^4\) and 20 01 40\(^5\). A full description of this work is available in Ryan-Fogarty et al 2020(a;b).

Data sampled in the scrap metal collections was similarly assigned weights based on the UNU Keys. In order to compare across categories, each UNU Key from the scrap metal was consolidated into categories from the six waste treatment processes at the compliant facility (Fig. 3.3) based on how that type of WEEE is treated. Amounts for each consolidated category were summed and compared with the corresponding FTE job number per weight of WEEE, resulting in the number of jobs the WEEE in scrap metal would result in were it diverted to the compliant facility.

4. Results

The tools and equipment used in the treatment of each category of waste, along with treatment processes and legally mandated pre-treatments, are listed in the following section. This section also presents the results of analyses calculating the amount of WEEE equating to one full-time job in WEEE treatment at the model facility.

Loading and unloading does not account for a large portion of the labour requirement in WEEE treatment yet is an important contributing part of the process.

4.1. Mixed waste

An incoming mixed stream of electronic waste is moved directly from trucks into the treatment area and sorted continuously throughout the day. The first sort is conducted manually, separating equipment to be entered into streams for which there are dedicated processing lines on-site (refer back to Fig. 3) as well as removing pieces unsuitable for subsequent mechanised process such as cables, glass, and products containing batteries, the latter of which will re-enter the mixed waste stream post battery removal. The remaining waste consists largely of small household appliances and other miscellaneous products (Fig. 4.1).

The first stage of pre-treatment, as mentioned, removes unsuitable waste from the stream and reallocates it into appropriate streams. The second stage uses a mechanical claw to separate items and drop them onto a conveyor belt where the workers further identify unsuitable materials, particularly cables (Photo 4.1). In the third and final stage, waste moves through a series of machinery including a large tumbler using gravity to break equipment into pieces, shredders, and machines using material separation techniques, with a number of workers manually separating smaller parts unsuitable for the machinery such as batteries and sorting material types at different stages.

As the conveyor belts and picking of unsuitable materials run continuously throughout the work shift, estimation of labour required is not broken down into tasks for this waste stream. Rather, the estimation is calculated from the number of workers and the amount of waste treated per day. Each day the mixed waste stream is reported to treat 25-30 tonnes of WEEE, running over an 8-hour workday with the help of approximately 15 workers. Within the range of WEEE per day, 362-453 tonnes of mixed WEEE equates to 1 full-time equivalent job.

![Fig. 2.1. Flows and categorisation of WEEE in the model facility.](image-url)
Fig. 3.3. a and 3.3b. A visual representation of the expression used to estimate labour hours (a) and/or weight of WEEE (b).

Fig. 4.1. Treatment flow of mixed waste at the model facility.

Fig. 4.1b. Mechanical & manual picking in mixed waste.
4.2. Large household appliances (LHA)

The separated collection source of LHA was unloaded at a rate of on average 16 seconds per unit, or approximately 0.37 minutes per 100 kg. While all LHA was segregated together and underwent largely the same treatment, washing machines underwent an additional manual treatment step consisting of the removal of the motor, purely for additional value recovery. Other LHA, along with the remaining portion of washing machines, was subsequently compacted and baled, largely for efficiency in transportation, then loaded for export for final treatment.

The LHA analysis resulted in two separate estimates, based on UNU code 0104 for washing machines, and an average of codes associated with other LHA product types. The treatment for LHA, not including washing machines, was found to require a labour input of 5.51 min/100 kg, while washing machines required 6.41 min/100 kg with the additional dismantling process.

The overall treatment process for LHA was estimated to equate to 1,967 tonnes per full-time job, while the treatment process for washing machines resulted in a slightly higher labour requirement with one full-time equivalent employee treating 1,692 tonnes in one working year.

4.3. Screens

4.3.1. Cathode ray tube (CRT) televisions and monitors

Separate collection occurred for a significant portion of CRTs treated, although a stream of units were separated from the mixed waste as well. CRT units were gathered in cages and moved by forklift to the workstation, where workers are located at ergonomic desks with hammers, electric screwdrivers, a conveyor belt leading to the depollution area, and easy to reach collection bins for separated materials (plastic/metal/etc.)

Following dismantling of the outer case the remaining inner glass casings were moved down the conveyor belt where the units were depolluted using a powder vacuum, and glass types are separated. Separated metal, plastic and glass was baled and removed from the area via forklift. The treatment process described here and illustrated in Fig. 4.3.1 equates 476 tonnes of CRTs within 1 full-time job.

4.3.2. LCD/LED displays

Flat-panel display televisions and monitors with backlighting provided through LEDs and LCDs are treated separately from CRT televisions, and also are largely received through separate collections. Although LCDs require an extra depollution step, in this facility by way of a specialised machine, all other processing in the model facility was the same for LED and LCD devices. Screens were delivered in cages and pallets to the workstation by forklift, where workers removed the housings using hammers and electric screwdrivers. Based on the weight estimated for UNU code 0309, the treatment process for flat-panel display TVs and monitors overall (Fig. 4.3.2) equated to 1 full-time job per 338 tonnes.

4.4. Microwave ovens

Microwave ovens were largely sourced as a separate collection in order to facilitate necessary removal of parts. A smaller portion was continuously sorted out from the mixed waste stream due to their construction being unsuitable for the machinery used to treat mixed waste. Illustrated in Photo 4.4, the process for treatment of microwave ovens included loading and unloading by forklift with a dismantling step...
where several component parts were removed manually in between. Manual dismantling was facilitated by an ergonomic work desk with attached tools hanging at easy reach, tools including an electric screwdriver and a hammer as the most frequently used. Pallets with units to be treated and bins for units to be taken away were placed within reach of the work desks.

Manual dismantling steps took an average of 1.5 minutes per unit, and each unit was estimated to weigh 18.21 kg according to UNU Key 0114 (Forti et al. 2018). Thus, with the added 2 minutes per tonne for both loading and unloading, microwave oven treatment at the model facility (Fig. 4.4) results in one full-time job per 1266 tonnes of microwave ovens.

4.5. Cooling

This equipment requires specialist treatment, which is not conducted in the Republic of Ireland and therefore was only loaded from collection trucks and reloaded into transfer trucks to specialised treatment facilities in Northern Ireland (Fig. 4.5).

Forklifts were used to move one pallet of several units at a time. Using the weights associated to UNU-Keys 0108, fridges (incl. combo fridges), and 0109, freezers, 40 and 44 kg respectively (Forti et al. 2018), the process of moving the pallets or units from one truck to another required approximately two minutes per tonne or 0.2 minutes per 100 kg. In this case it is not particularly useful to present labour hours in terms of full-time jobs, since on its own loading and unloading of 13,407 tonnes of cooling equipment at the model facility would equate to one full-time job.

4.6. Summary of time study and observation of compliant WEEE treatment

Comprised of an overview of the processing for 75% of collected Irish WEEE, the results stemming from this study present an interesting and largely representative view of Irish job creation in the recycling of electronics, consolidated in Table 4.

5. Discussion

The job equivalencies for the six categories of waste considered in this study have a very wide range, from 338 tonnes of Flat Panel Displays for one full-time job equivalent as the most labour intensive treatment category to 13,407 tonnes for cooling equipment as the least labour intensive category. Clearly, while the transport of cooling equipment from the Republic of Ireland into Northern Ireland where it is processed will account for a larger number of labour hours, pre-treatment of refrigerators and freezers is not a significant portion of the labour in recycling of WEEE within the Republic of Ireland. On a much more relatable scale, microwave ovens were the next least labour-intensive requiring 1,266 tonnes of microwave ovens to equal one full-time equivalent job, with LHA in a similar range. Microwave ovens also likely represent a smaller and lighter incoming stream and as such comprise a smaller portion of jobs in recycling than the remaining streams. The remaining streams, screens (including CRTs and LED/LCDs), and mixed waste, fall roughly into a much more similar range of 400-660 tonnes per one annual full-time equivalent job. These categories also represent high volumes and/or high weights being processed in the recycling facility, with LHA being a significant portion by weight considering the high weight of each individual units. Therefore, these
categories are particularly important in estimating job creation based on recycling of WEEE in Ireland.

The results of this study show the potential for job growth in not only the energy sector as estimated by the ILO (2018), but in the WEEE sector as well. The results also provide additional encouragement for establishing decent work opportunities in similarly facilities in developing nations as part of the previously mentioned (Section 2.1) Best of 2 Worlds philosophy (Wang et al. 2012). However, as discussed at length in section 2.1, it is difficult to compare the pieces of work in the existing WEEE job creation literature due to differing variables of scope such as economic, societal, regulatory environments, time frames, branches of the treatment process, etc.

Although the results do not illustrate employment and labour hours in collection, administration, refurbishment, or specific waste streams collected under separate schemes such as IT equipment, these jobs should also be considered in the quantification and related considerations of employment in recycling of WEEE. Pini et al. 2019, discussed previously in Section 2.1.1, identifies the job creation potential in preparation for re-use of WEEE and the implication that the additional step of preparation for re-use between disposal and recycling will contribute to more jobs. However, in Ireland the nature of WEEE treatment provides a limitation to the application of this method, in that preparation for re-use does not currently occur for WEEE collected in the Republic of Ireland (McMahon et al. 2019). Research by Coughlan and Fitzpatrick (2020) showed that 28% of laptops, tablets, and smartphones sampled in targeted collections were suitable for preparation for re-use. Comparing the results of this study and the results of this paper under the findings of job creation potential in Pini et al. provides further encouragement for the development of a preparation for re-use sector in Ireland. Quantification of these types of jobs creates opportunity for further related research, especially comprehensive research representing the entire sector and applicable to the same sector in various areas of the world. This model will be particularly interesting for use in better estimating the potential for decent work in developing nations, where recycling jobs would require a lower amount of automation, transitioning from informal WEEE recycling.

### 5.1. Application of time study and observational data to WEEE lost to scrap metal in Ireland

As stated in Ryan-Fogarty et al. 2020, “3.91% +/- 1.88% of the scrap metal sampled was estimated to be WEEE. This puts WEEE in the range of 2.03% to 5.79% with a confidence level of 95%. Scaling this for the 2018 data for the LoW codes of interest gives a figure of 10,950 tonnes +/- 5,265 tonnes which translates to a range of 5,685 tonnes to 16,215 tonnes”. The results in the later Section 5.1 show estimates based on the averaged figure of 10,950 tonnes of WEEE passing through scrap yards in Ireland each year.

Given that the mandated pre-treatments occur in the model recycling facility and do not occur in the scrap yards a significant labour difference in the processing of WEEE between the two site types is expected. Combining the results of both studies (Table 5.1) shows this assumption to be true for all bar temperature exchange equipment. Given that the treatment of temperature exchange equipment such as refrigerators and freezers is conducted outside of the Republic of Ireland, this category is not of particular importance in this comparison, as there is very little labour difference between the two sites (although where the material travels to and how it is treated at leaving both sites differs greatly). However, WEEE found in scrap yards representative of the other five categories does show a significant labour difference, particularly when summed together. It is also important to note that since WEEE at non-compliant facilities is not treated, and is in low amounts compared with the overall metal waste treated, WEEE diverted from non-compliant facilities to compliant ones does not result in a loss of jobs at the non-compliant facility. In fact, designating employment opportunity for a worker to oversee the separation and diversion of WEEE could result in an additional labour requirement.

The studied facility treatment category of mixed waste represented the highest amount of WEEE found in non-compliant facilities by weight, accounting for 35.46% of the observed WEEE. Washing machines (UNU Code 0104) comprised the highest single category of WEEE found in non-compliant facilities by weight, accounting for 20.79%, followed closely by household installed central heating (UNU Code 0001) at 20.54. Calculated with the job equivalency for mixed waste treatment of 362-453 tonnes of mixed waste resulted in 1 full-time job in recycling, it is estimated that the amount of mixed waste improperly

### Table 4.6
Summary of results, including annual full-time job equivalencies of waste treatment streams, treatment processes and equipment required at the model facility.

| Process in WEEE Treatment (min/100 kg) | Washing Machine | LHA | CRT | LED/LCD | Microwave Ovens | Cooling | Mixed Waste |
|---------------------------------------|----------------|-----|-----|---------|-----------------|---------|-------------|
| Unloading/Transfer                    | 0.37           | 0.37| 0.4 | 0.2     | 0.81            | n.a.    |             |
| Manual Dismantling                    | 0.9            |     | 0.2 | 0.7     | -               | n.a.    |             |
| Mechanical Dismantling                | -              | -   | -   | -       | -               | n.a.    |             |
| Depollution                           | -              | -   | 5.27| 12      | -               | n.a.    |             |
| Baling                                | 4.6            | 4.6 | 4.52| -       | -               | n.a.    |             |
| Compacting                            | 0.34           | 0.34| -   | -       | -               | n.a.    |             |
| Loading                               | 0.2            | 0.2 | -   | 1       | 0.2             | n.a.    |             |
| **Required Equipment for WEEE Treatment** | x              | x   | x   | x       | x               | x       |             |
| Forklift                              | x              | x   | x   | x       | x               | x       |             |
| Hammer/ Screwdriver                   | x              | x   | x   | x       | x               | x       |             |
| Wire Cutter                           | x              | x   | x   | x       | x               | x       |             |
| Specialised Depollution               | x              | x   | x   | x       | x               | x       |             |
| Baler                                 | x              |     | x   | x       | x               | x       |             |
| Compactor                             | x              |     | x   | x       | x               | x       |             |
| Machinery for Dismantling             | x              |     | x   | x       | x               | x       |             |

### Table 5.1
Application of technical coefficients representing jobs per tonne of WEEE to estimations of WEEE in scrap yards annually.

| Category     | Annual Estimated Weight in Scrap Yards (tonnes) | Estimated job equivalencies |
|--------------|-----------------------------------------------|-------------------------------|
| Mixed Waste  | 3,883                                        | 8.57 – 10.72                  |
| Washing      | 2,277                                        | 1.35                          |
| Machines     |                                              |                               |
| Other LHA    | 2,570                                        | 1.3                           |
| Microwave ovens | 430                                          | 0.34                          |
| CRTs         | 127                                          | 0.27                          |
| LED/LCDs     | 71                                           | 0.21                          |
| Cooling      | 1,395                                        | 0.1                           |
| Other        | 197                                          | n.a.                          |
| **Total**    | 10,950                                       | 12.14 – 14.29                 |
disposed of in scrap yards would result in approximately 8.57-10.52 full-time jobs in WEEE pre-treatments. Diversion of improperly disposed of washing machines contributed to the second highest job equivalency with 1.35 full-time jobs, and household installed central heating, appropriately pooled for calculation purposes into the LHA category of treatment at the compliant facility, also contributed along with other LHA to a significant estimate of 1.3 full-time jobs were this equipment diverted back to the appropriate channels. When combined with categories of treatment based on how they would be treated at the model facility the remaining quantities contribute to an approximate 1 additional job.

6. Conclusion

This study presents a rare quantitative estimate of the potential for job creation in WEEE treatment based on primarily collected observation data, particularly under EU legislation and standards. Furthermore, the potential for application of this estimate has been illustrated in the analysis of lost job creation potential in Irish WEEE not arising. Non-compliant treatment and disposal of WEEE, especially in the form of scavenging, has been established to have an economic impact on the WEEE recycling trade. Specifically, the differences between compliant and non-compliant facility costs create unfair competition and value loss by diverting equipment away from proper treatment channels (Baldé et al. 2017, Huisman et al. 2015). It is clear that due to the preparation for, reporting of, and the practice of becoming and remaining compliant there is a significant added cost and labour requirement. Non-compliant facilities and streams are not burdened by these added costs. In the highly regulated Irish system these differences in the cost base would be expected to be stark. This study shows this to be true in the comparison between WEEE improperly disposed of in scrap yards, where WEEE has been shown to not be separated and is processed as scrap, and compliant facilities such as the observed model facility, where WEEE is carefully separated and treated under regulatory and standard requirements. The combined implications of the non-compliant WEEE quantification and the estimation of labour hours per mass of categorised WEEE provide a unique perspective on the distinctions between compliant and non-compliant treatment.

The WEEE lost to improper treatment has the potential to create and support a likely minimum of 12-14 full-time equivalent jobs. It is important to acknowledge as a limitation of the scope of this study the employment potential in collection, administration, and other peripheral activities (such as preparation for re-use, for which limitations were previously discussed in Section 5) that are yet to be measured, as well as the employment potential in WEEE that is diverted into export, household waste collections (which may end up in landfills, incinerators, or plastics recycling), scavenging, and even long-term storage. Several factors further indicate that this is a conservative estimate. For instance, other waste streams enter scrap processors that contain WEEE, however, factors further indicate that this is a conservative estimate. For instance, Benoît, C., Norris, G.A., Valdivia, S., Ciroth, A., Moberg, A., Bos, U., Prakash, S., Ugaya, C., Beck, T., 2010. The guidelines for social life cycle assessment of products: just in time! Int. J. Life Cycle Assess. 15 (2), 156-163.

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