INFORMAL AND SEMI-FORMAL ELECTRICAL AND ELECTRONIC WASTE (E-WASTE) MANAGEMENT: A SOCIO TECHNICAL STUDY OF RISKS, PERCEPTIONS, INTERVENTIONS, AND EDUCATIONAL OPPORTUNITIES

by

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ABSTRACT

The expansion of technology in the 21st century is accompanied by a growing production of electrical and electronic equipment (EEE), including laptops, cellphones, refrigerators, kitchen appliances, and toys. The global consumption of EEE is increasing annually by 2.5 million metric tons, generating one of the fastest-growing waste streams in the world, known as “e-waste” or “WEEE.” Throughout the last decade, because of the complexity of its management and the toxicity and high relevance of many materials in EEE, e-waste was prioritized in the agendas of various international organizations. Furthermore, this waste stream is becoming an increasingly important source of income for many vulnerable communities. In this context, research has begun to focus on the environmental and health risks for informal e-waste workers, their families and neighbors.

While most projects and studies have assessed effects on women and children in Africa or Asia, very few have aimed to assist low-income workers in Latin America to apply the best management practices and reduce risks with a simultaneous positive impact on their economies. To contribute to filling this gap, through a mixed-methods and participatory approach, this thesis identifies chemical risks and risk perceptions in two informal and semi-formal e-waste management scenarios in Buenos Aires (Argentina). Then, it proposes risk reduction interventions based on the NIOSH Hierarchy of Controls and the Engineering and Sustainable Community Development criteria. Targeting five main audiences (workers, governmental officials, scholars, professors, and students), this study motivates the incorporation of e-waste as a topic for engineering education and encourages research and action toward occupational safety in non-formal settings. Finally, it recommends a focus on not only the environmental and health protection of workers and their communities but also the socio-economic development of these “invisibilized waste management heroes.”

TABLE OF CONTENTS

ABSTRACT iii

LIST OF FIGURES viii

LIST OF TABLES ix

ACKNOWLEDGMENTS x

DEDICATION xi

CHAPTER 1 INTRODUCTION 1

1.1 Thesis Introduction 1
1.2 Background and Motivation 2
1.3 Literature Review 6
1.3.1 Electrical and Electronic Waste: Global Trends 6
1.3.2 Informal Waste Management in Argentina: Historical and Socio-economic Background 8
1.3.3 Environmental Health Aspects Related to Informal E-waste Management Practices 9
1.3.4 Intervention Strategies to Reduce Risks in the E-waste Management Sector 10
1.4 Research Questions and Significance 13
1.5 Research Approach and Methods 15
1.5.1 Preliminary Study and Preparation Before Traveling (March-July 2022) 16
1.5.2 Fieldwork (July-August 2022) 17
1.5.3 Data Analysis and Writing Process (July- March 2023) 17
1.6 Chapters Overview 18

CHAPTER 2 CHEMICAL RISKS AND PERCEPTIONS ASSESSMENT IN TWO INFORMAL AND SEMI-FORMAL E-WASTE SITES IN ARGENTINA: A MIXED-METHODS ANALYSIS 20

2.1 Introduction 20
2.1.1 Global E-waste Trends, Informality, and Health Impacts 20
2.1.2 E-waste in Argentina 21
2.2 Methods and Materials 23
2.2.1 Study Design and Ethics 23
2.2.2 Literature Review 23
2.2.3 Interviews 24

2.2.4 Observation 24
2.2.5 Workshops 24
2.2.6 Semi-quantitative Risk Assessment 25
2.3 Sites Description 26
2.3.1 Site A: A Neighborhood with Moderate E-waste Activity 26
2.3.2 Site B: Solid Waste Cooperative Transitioning Into E-waste 31
2.4 Semi-quantitative Chemical Risk Assessment: Open Burning of Copper Cables 35
2.4.1 Problem Formulation 35
2.4.2 A Conceptual Model for the Study of Open Burning of E-waste at Site A and Site B 36
2.4.3 Hazards Identification and Characterization 38
2.4.4 Exposure Assessment 41
2.4.5 Risk Characterization 44
2.4.6 Conclusions of the Risk Assessment 48
2.5 Workers' Risk Perception 49
2.6 Conclusions 52
CHAPTER 3 INTERVENTIONS TO PROMOTE SAFER WORKING CONDITIONS IN INFORMAL AND SEMI-FORMAL E-WASTE RECYCLING SETTINGS: THE CASE OF COPPER CABLE TREATMENT 54
3.1 Introduction 54
3.1.1 E-waste Interventions: State of the Art in Argentina 55
3.2 Objectives 57
3.3 Methods 57
3.3.1 NIOSH Hierarchy of Controls 58
3.4 Applying the Hierarchy of Controls in the context of the open burning of copper cables at the study sites 58
3.4.1 Elimination 59
3.4.2 Substitution 61
3.4.3 Engineering Controls 68
3.4.4 Administrative Controls and PPE: Designated use of Land, Provision and Use of PPE, and Education 69
3.5 Analysis of the Hierarchy of Control Proposals Based on the Adapted ESCD Framework 74
3.6 Conclusions 77
CHAPTER 4 INCLUSIVE URBAN MINING: AN OPPORTUNITY FOR ENGINEERING EDUCATION 78
4.1 Introduction 78

4.2 Objectives 80
4.3 Description of the Study Sites 81
  4.3.1 C&WD in Colombia 81
  4.3.2 E-waste in Argentina 82
4.4 Methods 83
  4.4.1 Participatory Framework and Ethical Considerations 83
  4.4.2 Semi-structured Interviews 84
  4.4.3 Participatory Observation 85
  4.4.4 Workshops 85
  4.4.5 Research Extension with Colorado School of Mines Undergraduate Students 86
  4.4.6 Preliminary Review of Mining Engineering Curricula 87
4.5 Inclusive Urban Mining in Latin America 87
  4.5.1 Why Should Urban Mining be Inclusive? Some Examples of Its Social Benefits 88
  4.5.2 Environmental Benefits of Urban Mining 91
4.6 Inclusive Urban Mining in US Engineering Curricula 92
  4.6.1 Preliminary Screening of Urban Mining Content in the US Engineering Programs 92
4.7 Approaches to Include Urban Mining in US Engineering Curricula 93
  4.7.1 Introducing Urban mining to First-year Engineering Design Courses 93
  4.7.2 Introducing Urban Mining in Elective Courses: the Case in an Engineering and Sustainable Community Development Course 95
  4.7.3 Introducing Urban Mining Projects in Third and Fourth-Year Project-Based Design Courses 97
4.8 Conclusions 98
4.9 Acknowledgments 99

CHAPTER 5 THESIS CONCLUSIONS 101

5.1 Main findings 101
5.2 Limitations of this study and some other considerations 103
5.3 Research translation and extension commitments 104
5.4 Recommendations for future work 104

REFERENCES 106

APPENDIX A ADDITIONAL MATERIAL 122

A.1 E-waste-Related International Organizations, Associations, and Partnerships 122
A.2 General identification of chemical risks of e-waste management at Site A and Site B. 124

A.3 Other General identification of chemical risks of e-waste management at Site A and Site B 124
A.4 ACUMAR's EISAAR methodology 125
A.5 Suggested exposure descriptors for Sites A and B 125

APPENDIX B APPENDIX B. SUPPLEMENTAL FILES AND PERMISSIONS 126

LIST OF FIGURES

Figure 1.1 Key instances for the development of the thesis. 16

Figure 2.1 Site A delimited by purple lines (ACUMAR 2018b). 26

Figure 2.2 (a) Micro-dump at Site A (Author). (b) Mixed waste collected by an urban recoverer (Antolini, 2022). 28

Figure 2.3 (a) E-waste and other waste streams accumulated on the street at Site A (Author). (b) Mixed waste in the local cooperative located at Site A (Author). 28

Figure 2.4 (a) Open burning of cables in Buenos Aires (ACUMAR, 2022). (b) Ashes on the ground after suspected open burning at Site A (Author). 29

Figure 2.5 Map with the responses of the five groups (G1-G5) that participated in the workshop at Site A (Author). 30

Figure 2.6 Sign of a small metal buyer shop at Site A that reads “I buy copper, bronze, aluminum, profiles, lead, refrigerator compressor, battery” (Author, translated from Spanish). 31

Figure 2.7 Site B delimited by red lines. (Google Maps. 2023 CNES / Airbus, Maxar Technologies 2023) 32

Figure 2.8 E-waste sector at Site B (indoors) (Author). 33

Figure 2.9 E-waste sector at Site B (outdoors) (Author). 34

Figure 2.10 The conceptual model for the study of open burning of copper cables (Author). 36

Figure 2.11 (a) Sample of cables at Site B categorized as “Cables” (Author). (b) Sample of cables at Site B categorized as “Computer cables” (Author) 38

Figure 2.12 Three-core belted cable (Murty, P. S. R., 2017). 39

Figure 3.1 Prototype of a low-cost wire stripper (Author. Adapted from Backyard Art, 2020) 62

Figure 3.2 Schematic representation of electromechanical stripping (Author). 65

Figure 3.3 Example of a densiometric table built by an e-waste worker in Buenos Aires. (G. L. Clinckspoor & Zulaica, 2022) 66

Figure A.1 Steps in ACUMAR's EISAAR methodology. 125

LIST OF TABLES

Table 2.1 Main combustion products released during the open burning of cables, their effects, and reference doses. 40

Table 2.2 Not comprehensive literature review of risk characterization for the burning of e-waste (occupational-related scenarios).. 45

Table 3.1 Literature review of Argentinian e-waste-related publications. Not comprehensive.......... 55

Table 3.2 Comparison between the open burning and low-cost stripping process. 63

Table 3.3 Description of factors used to analyze each proposed intervention under the adapted ESCD criteria. 74

Table 3.4 Comprehensive analysis of the OSC proposals in the context of Site A. 75

Table 4.1 Preliminary Review of Mining Engineering Curricula related to urban mining and sociotechnical learning approaches in the US. 93

Table A.1 List of some e-waste-related international organizations, associations, and partnerships 122

Table A.2 Preliminary identification of chemical risks of e-waste management at Site A and Site B 124

Table A.3 List of other EEE potentially burned at Site A and their components (not comprehensive) 124

Table A.4 Suggested exposure descriptors for Sites A and B 125

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For the invisibilized waste management heroes
(and other invisibilized heroes).

CHAPTER 1
INTRODUCTION

1.1 Thesis Introduction

As in many other parts of the world, general waste management (including recovery, reuse, repair, refurbishment, and recycling) is a source of income for some families in Argentina. National reports indicate an increasing trend of formal and informal workers in this activity due to the successive national economic crises since the 1990s, the COVID-19 global pandemic, and growing waste production (Carenzo, 2017; Castillo et al., 2022; G. L. Clinckspoor & Ferraro, 2020; Maffei & Burucua, 2020; Schamber, 2006; Schettini & Herrero, 2017). In particular, the people who informally recycle electrical and electronic waste (e-waste) often work in unsafe conditions, and their practices unintentionally contribute to negative environmental and health impacts in their communities. For example, a governmental agency in Buenos Aires studied three neighborhoods in 2017-2018 and found more than 200 children with high levels of lead in their blood due to their exposure to emissions from the burning of e-waste close to houses and playgrounds (Comesaña García, 2019). Some researchers claim workers lack sufficient information to perceive these risks and to take risk reduction measures (G. L. Clinckspoor & Ferraro, 2020; Davey & Walsh, 2019; World Health Organization, 2021a). However, most projects and studies focus on assessing health and environmental-related effects in women and children, and very few efforts are aimed at assisting the workers in applying the best e-waste management practices to prevent and reduce the risks to which they, their families, neighbors, and the environment are exposed (Arain & Neitzel, 2019; World Health Organization, 2021a). In this context, some authors claim that “one of our greatest challenges of the next decade” is to “(move) scholarship toward devising and assessing more sustainable solutions that are participatory and fair to low-income workers” (Daum et al., 2017, p. 15).

To contribute to filling this gap, this thesis is focused on studying interventions to reduce chemical risks in the informal and semi-formal e-waste management sector in two sites in Buenos Aires. Its objective is to provide concrete recommendations for specific risk management interventions to be implemented in the study sites by targeting three audiences: e-waste workers, local governmental agencies, and scholars. The recommendations proposed are based on detailed site-specific descriptions of the activities and impacts and a participatory evaluation process with local stakeholders.

This thesis is expected to provide data and recommendations for regulators, in particular the ones with whom I interacted the most that are interested in moving forward with policies and programs to reduce chemical risks. As for the workers, their families, and neighbors, I expect to raise awareness of health and environmental risks to promote the incorporation of healthier habits within the local community while supporting their local socio-economic development. To extend my research, I aim to bring this work to other engineering and science students' attention and promote future lines of research that might be materialized as academic theses or projects. Moreover, through two planned publications in relevant peer-reviewed journals, I hope to contribute to the academic work of engineering, environmental and occupational health, and community development professionals, educators, and scholars interested in studying and improving living and working conditions in e-waste informal and semi-informal contexts, with careful attention to the socio-economic development of these vulnerable communities.

From a macroscale perspective, implementing proper e-waste management practices will lead to multiple benefits in the long term. On the one hand, recovering materials to be reintroduced into productive chains reduces waste and the extraction of expensive and scarce raw materials. On the other hand, this labor-intensive sector has the potential to generate stable, secure, formal, economically sufficient, and decent green jobs[1] and promote a better quality of life for a number of workers and their families (Maffei et al., 2020).

The objective of the Introduction chapter is to present the background information and motivations that originated this study, accompanied by the literature review on the main areas of interest: i) global and national e-waste scenario, ii) informal and semi-informal e-waste management, iii) environmental health aspects related to e-waste management practices, and iv) global experiences of interventions to reduce risks in the e-waste management sector. Then, I present my three research questions, the research approach and methods, and finally, an overview of the three chapters of this thesis[2].

1.2 Background and Motivation

Interviews with members of the government, academia, and civil organizations[3] in conjunction with a preliminary literature review helped me refine my thesis topic during Fall 2021 and Spring 2022. First, I

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[1] The International Labour Organization defines green jobs as “decent jobs that contribute to preserve or restore the environment, be they in traditional sectors such as manufacturing and construction, or in new, emerging green sectors such as renewable energy and energy efficiency.” (International Labour Organization (ILO), 2016). Decent work is the term for “productive work in which rights are protected, which generates an adequate income, with adequate social protection. It also means sufficient work, in the sense that all should have full access to income-earning opportunities.” (International Labour Organization, 1999)

[2] It is worth clarifying that throughout this thesis, there are two different ways of addressing readers. The first-person singular is used in the Introduction chapter and Chapter 5 (Conclusions). In chapters 2, 3, and 4 (potential co-authored papers), the first-person plural is the preferred voice.

[3] Academia: Director of the Master in Sustainable Urban Technologies (National University of Buenos Aires), CONICET Researchers in the Institute for Social Studies of Science and Technology (National University of Quilmes) and the Habitat and Environment Institute (National University of Mar del Plata). Governmental agencies: Environmental Toxicology Team, Department of Health and Environmental Education, Matanza-Riachuelo Basin

learned about environmental and health risks associated with the informal e-waste recycling sector. The topic was deeply related to my academic background in chemical engineering, toxicology, and ecotoxicology. It was also linked to my previous experience as a Technical Advisor in the National Directorate of Chemicals and Hazardous Waste at the National Ministry of Environment and Sustainable Development in Argentina (2018-2020), where I learned about multilateral environmental agreements addressing e-waste (e.g., Stockholm, Basel, and Minamata Conventions). I also found that local data were available to qualitatively describe the current sanitary and environmental situation in some neighborhoods in Buenos Aires. With this in mind, instead of following the general academic trend of analyzing the risks, I decided to focus on the second step in the risk assessment and management paradigm: risk management (US National Research Council, 1983). Under this framework, I am following a novel approach by conducting research in such specific settings while considering the local context and knowledge in addition to the international experiences.

The scope of this work builds on three main aspects:

1. The research is limited to two specific contexts, the *informal* and *semi-formal* e-waste management sector. *Informal* refers to a sector of the economy that is not regulated[4], which is usually characterized by vulnerable and precarious settings. In the context of this study, this term includes the "urban waste recoverers" (a concept used by Gutberlet (2009) and further described in Chapter 2) as well as the cooperatives[5] that are not transitioning into formality yet. For the purpose of this study, s*emi-formal* is a term used to name the sector that is under the transition from informality to formality. For example, solid waste cooperatives that are incorporating e-waste management into their activities. *E-waste* covers several categories of electric and electronic devices, components, and materials[6]. However, due to time and data

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Authority (ACUMAR), and Ministry of Environment of the Province of Buenos Aires. E-waste programs: Nodo Tau (Rosario, Santa Fe) and Ekoa (ex "E-Basura," National University of La Plata). E-waste consultant (Buenos Aires). Cooperatives: "Cooperativa Reciclando Trabajo y Dignidad" (Buenos Aires City), "Cooperativa TecnoRAEE" (Pilar, Buenos Aires), and "Cooperativa Villa Itatí" (Quilmes, Buenos Aires).

[4] In 2002 the ILO (International Labor Organization) defined informal work as a work activity carried out outside the legal regulatory framework, characterized by an insertion vulnerable and precarious (Schettini, P. and Herrero, V. 2017).

[5] Cooperatives are "autonomous associations of persons united voluntarily to meet their common economic, social and cultural needs and aspirations through a jointly owned and democratically controlled enterprise" (ILO *Recommendation R193: Promotion of Cooperatives, 2002*).

[6] E-Waste (also known as WEEE, waste of electrical and electronic equipment) is used to cover items of all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of reuse. EEE includes "any household or business item with circuitry or electrical components with power or battery supply." (Step Initiative, 2014)

constraints, this research is limited to the specific waste treated or with the potential to be treated by the workers in the sites under study, with special emphasis on copper cables. I selected *management* as a term to acknowledge the several practices –including but not restricted to recycling- that can be applied to dealing with electronic and electrical devices, for example, recovery, reuse, repair, and refurbishment.

2. Despite many other risks associated with informal e-waste management, including musculoskeletal hazards and hearing loss (Acquah et al., 2021; Burns et al., 2016, 2019), this study only focuses on chemical exposures. The decision to narrow its scope was based on my professional and academic background, and it is also related to time limitations. It was also supported by literature since one of the main concerns from the environmental health perspective is the exposure to hazardous substances (World Health Organization, 2021a).
3. Due to the time, location, and resource limitations of my master's thesis, I did not develop a technology-based intervention. However, as it is described in Chapter 2, I led two workshops for e-waste workers where the purpose was not only to obtain data but also to transfer knowledge about chemical risks. They received certificates for their participation in the workshop. This activity could be considered as an educational intervention. Furthermore, I conducted a solid semi-quantitative site-specific risk assessment and a preliminary study of possible interventions, which will inform and hopefully lead to real interventions from the government, academia, or other stakeholders.

This study fulfills the thesis requirements of the new Humanitarian Engineering and Science (HES) MS program because of following three reasons.

First, the purpose of this work is to popularize expert knowledge that is usually confined to governmental, scientific, and academic spaces. Data is usually generated and presented in a way that does not directly respond to the local communities' questions and interests. Studies are usually well-intended but lack answers to those whose lives depend on the "waste"[7] management. Thus, this work intends to provide information about the risks and prevention measures in a relevant and accessible way for them. To this end, I applied two essential approaches from the Engineering and Sustainable Community Development field, namely research extension (through participation in undergraduate courses, as described in Chapter 4) and research translation (through workshops, as described in Chapter 2) (Lucena et al., 2022).

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[7] The intentional use of quotation marks aims to call readers' attention to the need to reconsider waste and the value of massively discarded items.

Second, the design and implementation of this research, the analysis of data, and the design of the intervention proposals have been conducted under a socio-technical paradigm. It means that agreeing with Smith et al. (2021) in recognizing that engineering projects have both technical and social dimensions that affect each other, I benefited "from learning and applying qualitative, social-science, social-justice based strategies along with my previous technical skills" that allowed me to critically analyze the many factors and actors that may influence the risks, their identification, perception, and management (Gibson, C. 2022).

Under a socio-technical approach, the problems associated with e-waste management can be described and addressed beyond the traditional environmental health science perspective. The problems become a product of complex site-specific dynamics and structural inequalities, such as the existing obstacles for the local inhabitants to get stable, secure, formal, economically sufficient, and dignified jobs, the lack of inclusive regulations that protect and consider waste recoverers and cooperativists as part of the waste management system, and saturated public health systems that must address increasing structural threats to the local communities.

This approach is closely related to Dr. Ramón Carrillo's perspective about the Right to Health, highlighted by the Autoridad de Cuenca Matanza-Riachuelo (ACUMAR), the local governmental agency I partnered with in the context of my research project (ACUMAR, 2021)[8]. Dr. Carrillo challenged the hegemonic biomedical view of health and promoted a comprehensive conception that included dignifying people's living conditions through work, education, housing, adequate food, environmental sanitation, access to health services, leisure and recreation activities, the possibility of acting autonomously, making decisions, and taking part in community decision-making processes.

Third, the last and possibly the most crucial aspect of this work is that it is intended to serve informal and semi-formal e-waste workers, a group of people whose voices are usually not included in the academic literature (Daum et al., 2017). Therefore, this work aims to push the boundaries of research and practice into the complexity of cities, challenging traditional sustainable development projects usually focused on non-urban areas. Additionally, the two study sites are located in the Matanza-Riachuelo basin, one of Argentina's most inhabited and industrialized areas that allocates "the most visible environmental problem in the country" (ACUMAR, 2021). Considering the environmental deterioration and high population

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[8] In 2006, National Law No. 26,168 led to the creation of ACUMAR under the Ministry of Environment and Sustainable Development with competence in the area of the Matanza-Riachuelo Basin. It is an entity with significant expertise in the promotion of the safety of the inhabitants and the environment, and its objective is to develop and implement "healthy public policies" with the purpose of reducing the occurrence of diseases that are associated with exposure to environmental risk factors or with unsatisfied basic sanitation services (ACUMAR, Plan Sanitario 2019).

density that characterize the living conditions in this area, this research is intentionally focused on a group of people in a situation of high social vulnerability. With this work, I aim to provoke action on an essential environmental injustice, the unfair treatment of the people whose work contributes to climate change mitigation and facilitates the transition to the circular economy (GDFEEW. Points of Consensus., 2019; Gutberlet & Carenzo, 2020; Vergara et al., 2016). They are still marginalized, even when they receive what individuals and organizations discard for free and accept the costs of dealing with hazardous materials. Their practices are often considered “unskilled, marginal, and precarious“ (Ntapanta, 2021, p.7), yet e-waste workers are filling “enormous gaps left by the city's waste management systems” (ibid).

1.3 Literature Review

1.3.1 Electrical and Electronic Waste: Global Trends

The expansion of technology evidenced in the 21st century is accompanied by a growing production of electrical and electronic equipment (EEE), including laptops, mobile phones, refrigerators, washing machines, dishwashers, kitchen appliances, toys, and photovoltaic panels, among others. The Global E-waste Monitor 2020 (Forti et al., 2021) estimated that, on average, the total global weight of EEE consumption increases annually by 2.5 million metric tons (Mt) without considering photovoltaic panels. In Latin America, the report “Regional E-waste Monitor for Latin America: Results for the 13 countries participating in project UNIDO-GEF 5554” (Wagner et al., 2022) generated regional statistics based on information from 13 countries, evidencing an increase in EEE from 1.7 Mt to 1.9 Mt between 2010 and 2017. However, in 2019 the total amount of EEE placed on the market returned to its original value of 1.7 Mt, which has been attributed to economic crisis (ibid.). After the COVID-19 pandemic and the accelerated working-from-home transition that increased the demand for electronics, it is expected that the numbers of EEE placed on the market have gone beyond these statistics (G. L. Clinckspoor & Zulaica, 2022).

Likewise, the discarding of EEE generates waste, known as electrical and electronic equipment waste, e-waste, or WEEE[9], which is recognized as one of the fastest-growing waste streams in the world (GDFEEW. Points of Consensus., 2019; Lundgren et al., 2012; Wagner et al., 2022) and is expected to continue growing “at a significant rate” (GDFEEW. Points of Consensus., 2019). Forti et al. (2021) reported

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[9] StEP (Solving the E-waste Problem) Initiative defines that e-waste ‘cover(s) items of all types of EEE and its parts that have been discarded by the owner as waste without the intention of reuse’ (Step Initiative, 2014). This stream can be categorized in different ways. One category commonly adopted is the one from the European Union’s WEEE Directive, which is based on the treatment and has six main categories: 1) Temperature exchange equipment, 2) Screens and monitors, 3) Lamps, 4) Large equipment, 5) Small equipment, 6) Small IT and Telecommunication equipment.

that 53.6 Mt of e-waste were generated worldwide in 2019, but only 9.3 Mt were environmentally managed, representing less than 18%[10]. This is why throughout the last decade the management of e-waste was installed with force in the agendas of various international organizations, which developed a good number of reports on the economic situation, flow of materials, technology, health, environmental, and social at the international and national level. In Appendix A, Table A.1 describes some of these organizations and their work on the subject.

E-waste is a complex stream from various perspectives. From a composition perspective, EEE consists of up to 69 elements from the periodic table, including precious metals (e.g., gold, silver, copper, platinum, palladium, ruthenium, rhodium, iridium, and osmium), critical raw materials (e.g., cobalt, palladium, indium, germanium, bismuth, and antimony), and noncritical metals, such as aluminum and iron (Forti et al., 2021)[11]. In 2019, the demand for iron, aluminum, and copper to produce new electronics was approximately 39 Mt, mainly obtained by primary mining (ibid). At an environmental level, the increasing production of EEE intensifies the consumption of non-renewable resources and the generation of greenhouse gas emissions. Moreover, if the discarded artifacts are not properly managed, their materials—that could be reinserted in the production chain under the concept of the circular economy—end up incinerated, in landfills, or in open dumps with a potential to contaminate the environment (ibid). At the health level, this waste stream differs from others as it contains highly hazardous substances and its treatment becomes complex since, if carried out improperly, it can affect not only workers but also their families and neighbors (World Health Organization, 2021a). Other levels of study on e-waste include transition strategies toward the circular economy (PACE, 2021), stock flow analysis (Aldebei & Dombi, 2021), and transboundary movements, among others. From an occupational viewpoint, this waste stream is an increasingly important source of income for many people globally. However, not all e-waste workers live and work in stable, secure, formal, economically sufficient, and dignified conditions.

In particular, the International Labour Organization (ILO), one of the most relevant international organizations for this study, has addressed the challenges related to decent work in the e-waste sector since 2012. Recently, the ILO has reported that “it is of concern that many policies focus primarily on

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[10] It is worth mentioning that statistics on e-waste collected and recycled are based on reports by countries (Forti et al., 2021). During this research, some informants have stated that, at least in Argentina, the data about vandalized power cables are not accurately registered and might have not been included in these statistics.

[11] According to Grimes & Maguire (2020), countries in Europe and other “developed” economies have classified specific materials -particularly metals- as critical based on the risks associated to their availability and economic value. The definition of criticality depends on regions and countries. For example, the European Commission has published lists with critical materials based on their economic availability, political influences, ease of recycling, potential for substitution and likely development of new raw material sources.

environmental dimensions without giving sufficient consideration to socio-economic or employment effects of the transition to circular economies globally, regionally, nationally and in different sectors" (International Labour Organization, 2023, p.3). In light of these reflections, this work intends to address, specifically, the issue of e-waste from the perspective of decent work.

1.3.2 Informal Waste Management in Argentina: Historical and Socio-economic Background

1.3.2.1 Understanding the Roots of Informal Waste Management in Argentina

Many authors have illustrated how neoliberal policies implemented in Argentina in the 1990s increased unemployment and poverty , forcing many people who lived in marginalized conditions to use their skills and the few resources they had to obtain a minimum income that allowed them to support their families and themselves (Carenzo, 2017; Paiva & Banfi, 2016; Schaap & Slijkerman, 2018; Schamber, 2006). As a consequence, enhanced by a devastating national economic crisis in 2001 and other consecutives economic crisis since then, the activity of informal waste management has grown in the number of "cartoneros" (waste-pickers), in the number of "recuperadores urbanos" (urban-recoverers) (Carenzo, 2017; Gutberlet, 2008b), and in the amount of waste recycled (Schamber, 2006; Schettini & Herrero, 2017; Clinckspoor & Ferraro, 2020).

Cartoneros and urban recoverers are workers who collect and treat household waste. They often work in precarious conditions without protection from minimum labor rights. In recent decades, some of them, mainly from the province of Buenos Aires and the City of Buenos Aires, began joining cooperatives to formalize their activities and improve their working conditions (Schamber, 2006). Despite the extraordinary efforts of these workers and their high collection efficiency (Arain et al., 2022; Vergara et al., 2016), in the absence of regulations that recognize them as fundamental actors in the circular economy chain (G. L. Clinckspoor & Ferraro, 2020), they work in disadvantaged conditions compared to other large actors—such as private companies in charge of waste collection or final disposal— and their activities are affected by frequent fluctuations of the market and volumes of material collected (Castillo et al., 2022). Therefore, many of these workers reinvent themselves and discover alternative materials to collect and recycle. Consequently, with an increasing amount of electrical and electronic waste generated globally and nationally, accompanied by a competitive market of metals, this type of waste became a new horizon for cooperatives, cartoneros, and urban recoverers (Maffei & Burucua, 2020).

1.3.2.2 Informal E-waste Management in Argentina

The management of e-waste is considered an emergent activity in the country, and little is known about it[12]. Recent reports developed by national authorities confirm this data gap (Maffei et al., 2020), and the lack of regulations reveals that electronic waste management is a pending issue in Argentina. However, there are communities whose income depends on these materials. In total the ILO Office in Argentina estimated 34,1000 workers in the e-waste formal and informal sectors in 2019 International Labour Organization, 2019). Some sources estimated that 600 people worked in the informal e-waste recycling sector in 2017 at the national level, and the number grew to around 2,000 workers in 2019 mainly due to the economic crisis (Maffei & Burucua, 2020). A different source indicated 2,800 informal workers in 2019 in only 14 municipalities in the province of Buenos Aires (ibid.). These tremendous discrepancies further highlight the insufficiency of the available data.

A report published by ACUMAR, links high lead exposures to informal e-waste management and emphasizes the vulnerable situation in which these workers live and work (ACUMAR, 2018a). For example, they lack any labor rights, are exposed to hazardous substances and harmful labor practices, and often live in contaminated environments. Some additional references to environmental health studies conducted in Buenos Aires are described in the next section.

1.3.3 Environmental Health Aspects Related to Informal E-waste Management Practices

The global academic and gray literature illustrate informal practices such as manual dismantling, inappropriate shredding, open burning, heating, and acid leaching (Lundgren et al., 2012; Sepúlveda et al., 2010) with effects on the health of adults and children (Arain & Neitzel, 2019; K. Grant et al., 2013; Neitzel et al., 2020; Sepúlveda et al., 2010; Srigboh et al., 2016; World Health Organization, 2021a; Yohannessen et al., 2019). However, it is suggested that e-waste management workers, mostly not grouped or formalized, lack sufficient information to perceive the risks to which they, their families, and the local environment are exposed (G. L. Clinckspoor & Ferraro, 2020; Davey & Walsh, 2019; World Health Organization, 2021a).

Even though scholars recognize that risks and effects are closely linked to specific local practices, including devices collected and recycling processes, most of the studies are from China or Ghana (World Health Organization, 2021a) and very little is known about Latin America (Yohannessen et al., 2019). In this sense, it is important to emphasize that the activities related to e-waste management are site-specific.

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[12] This lack of information is also observed at the global level in relation to the e-waste workforce, as highlighted by Daum, K., Stoler, J., & Grant, R. J. (2017): “The voices of e-waste workers remain largely absent throughout the e-waste literature” (p. 11).

“Therefore, to establish (…) appropriate policies and safety measures while simultaneously maintaining economic flexibility for those involved, evaluation and understanding of the context should be completed first” (Yohannessen et al., 2019, p. 12).

At a national level, a preliminary literature review revealed only two scientific articles that studied three neighborhoods in Buenos Aires and identified more than 200 children with high levels of lead (Comesaña García, 2019; Zavatti et al., 2020). The burning of e-waste – mostly copper cables– close to houses and playgrounds has been identified as the most probable cause (ibid.). Only one report from a local authority mentions e-waste burning as an activity of concern (ACUMAR, 2018a). In 2018, this local agency detected 1,000 sites contaminated with lead in 13 neighborhoods in Buenos Aires. Hence, if environmental health data obtained from global research are extrapolated in the context of Buenos Aires, the assumptions made should be carefully analyzed (Burns et al., 2016).

1.3.4 Intervention Strategies to Reduce Risks in the E-waste Management Sector

1.3.4.1 Risk Management in the Informal E-waste Sector: A Global Perspective

Most scholarship and intervention projects on e-waste focus on studying health and environmental-related problems instead of local risk management strategies. The “E-Waste: Prevention Intervention Strategies Meeting 2017” report, developed by NIEHS, reads, “We know the adverse effects of mismanagement (of e-waste) on health. But at the end of the day, the people involved in these activities need solutions. We have to start assessing the effectiveness of the interventions so that countries can implement them” (NIEHS, 2017, p. 20).

Along these lines, as a result of an integrated review of e-waste recycling research specific to Agbogbloshie (Ghana)—one of the most studied sites at the global level— Daum et al. (2017) concluded that the major trend in scholarship is the study of impacts (on human lives, health, and communities) associated with risky practices. The authors claim that “moving scholarship toward devising and assessing more sustainable solutions that are participatory and fair to low-income workers presents one of our greatest challenges of the next decade” (Daum et al., 2017, p. 15). Other scholars indicate the need and importance of exploring local and simple methods, solutions, and improvements to minimize risks in the short term (Comesaña García, 2019; Heacock et al., 2018; Lundgren et al., 2012; Prakash et al., 2010), and to obtain better performance without sacrificing the economic and social benefits this activity offers to the local industry and communities (Chi et al., 2011).

As stated by Heacock et al. (2018), “while solutions to reduce exposure and protect human health must be locally tailored, we can learn valuable lessons from work that has been done to reduce exposures and protect health [and the environment]” (p. 221). Some guides on risk-reduction measures in the e-waste sector are available in the literature (Chou et al., 2021; Davey & Walsh, 2019; Schluep et al., 2015; Sepúlveda et al., 2010). For instance, the International Labour Organization in India (ILO India) has developed a checklist of low-cost risk reduction strategies to assist workers in improving their safety, health, and working conditions using locally available materials (World Health Organization, 2021a). Other examples of interventions are the applied research project "Enhancing Informal Electronic Waste Recycling Tools and Methods" conducted in Thailand by the Exposure Research Lab at the University of Michigan (2014-2016)[13], and the project "Transforming Agbogbloshie: From toxic dump into model recycling center" coordinated by Pure Earth in Ghana (2014-2016)[14].

1.3.4.2 Risk Management in the Informal E-waste Sector: Argentina

In addition to identifying some initiatives related to environmental and health education in specific neighborhoods of Buenos Aires (ACUMAR, 2018a), my exploratory literature review indicated that there were no previous interventions to minimize risk in the informal or semi-formal e-waste sector in the country. In relation to technological improvements, only one project designed by the Provincial Organization for Social and Urban Integration (OPISU) aimed to provide technical assistance to three cooperatives to characterize wastes, understand what could be treated and what type of specific knowledge in e-waste they needed (e.g., on market circuits and appropriate technology for recycling) (OPISU, 2021). At the time of the publication of this thesis, there was no accessible updated information on the progress of OPISU's project.

1.3.4.3 Interventions that Acknowledge the Local Community, Their Context, Knowledge, And Desires

Historically, many international development projects have resulted in failures, either due to an inadequate methodology for problem definition, over-attention to technology, or lack of involvement of community members during the assessment of proposed solutions, among other factors (Nieusma & Riley, 2010). Thomas et al. (2017) criticized projects in the development of national technology for social inclusion, pointing out two main failures that converge in nonworking institutional and technological solutions: 1) "reducing poverty and social exclusion to a technical problem" (p. 22), and 2) top-down, pro-poor intervention strategies and research efforts aimed to find "appropriate technologies" (ibid.). To enable long-term development strategies, they argue that the search for technological alternatives that activate

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[13] Retrieved in March 1, 2022 from: https://umexposureresearch.org/enhancing-informal-electronic-waste-recycling-tools-and-methods/

[14] Retrieved in March 1, 2022 from: https://www.pureearth.org/photos-transforming-agbogbloshie-from-toxic-e-waste-dump-into-model-recycling-center

inclusive development processes should involve users in framing the problem. In particular, in the e-waste management context, Heacock et al. (2016) call attention to the need for human-centered design, community participation, and research translation, pointing out that “improving environmental conditions where local concerns and needs are actively considered can be achieved through community-informed engineering solutions” (Heacock et al., 2016, p. 554).

With this in mind, it is crucial to highlight that recyclers have essential knowledge that must be studied from the outset, as they “are producers of knowledge and reality” (Daum et al., 2017, p. 11). The recycling sector in Argentina has a long history that deserves to be considered to design and analyze new e-waste management practices. However, very few local grass-rooted improvements of recycling technologies and practices have been published. The experience of the solid-waste cooperative “Reciclando Sueños” illustrated by Carenzo (2017) is the only example identified during the preliminary literature review. ACUMAR (2021) also proposes that local problems should be solved from the community dimension. They state that working with the participation of the extended beneficiary population allows the possibility of replicating practices in other workers and families (ACUMAR, 2021).

1.3.4.4 Criteria for Evaluating Socio-technical Alternatives

The Engineering and Sustainable Community Development (ESCD) criteria (Lucena, 2014) based on Bridger & Luloff's article (1999) provide a framework to assess interventions in humanitarian projects that might be applied for analyzing socio-technical alternatives to harmful practices within the informal e-waste management sector. Under this approach, for each proposed alternative, one should answer questions like:

- How does the proposed alternative enhance economic diversity while reducing dependency on external sources?
- Which measures are necessary to ensure that the community maintains local control, including maintenance and operation, without depending on outsiders?
- How can interventions lead to efficient use of energy and materials?
- What can be done to facilitate the fair allocation of rights, opportunities, and resources in order to enhance human capabilities and minimize risks and harm among community members?

In a previous work (Schlezak et al., 2022) my Thesis Committee members[15] and I adjusted these criteria to e-waste contexts to create a model that permits the evaluation and comparison of e-waste

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[15] In alphabetical order: Luciana Antolini, Alina Handorean, Juan Lucena, Richard Neitzel, and Oscar Restrepo Baena.

interventions in vulnerable contexts. We proposed that this model could be improved with inputs from local stakeholders. Additional information about this article is presented in Chapter 3.

Other e-waste-specific models, such as those presented by Huisman et al. (2019) and Rousis et al. (2008), include specific environmental, economic, technical, and social indicators and might complement the ESCD criteria framework. In all cases, without social cohesion and consensus among the various stakeholders that play a role, the sustainability of the waste management systems cannot be guaranteed (Clinckspoor & Ferraro, 2020). Therefore, interventions should acknowledge the several stakeholders that might be relevant for designing and implementing one or more activities (such as manufacturers, importers, distributors, formal and informal recyclers, consumers, government, academia, and NGOs). Also, some scholars and regulators suggest exploring different means of stakeholders partnerships, such as public-private partnership (PPP) model-based systems (Lundgren et al., 2012)[16]. Others recommend considering the concept of extended producer responsibility (EPR) for designing e-waste management systems (G. L. Clinckspoor & Ferraro, 2020; Fernández Protomastro, 2013; Magalini et al., 2015; McDonald et al., 2017; World Health Organization, 2021a).

1.4 Research Questions and Significance

Having conducted a thorough literature review in many disciplines, the following research questions were formulated from the gaps described above.

Research question 1: What are the chemical risks derived from the informal management of e-waste in the context under study, and how do the different stakeholders perceive them?

This research question was developed to understand and describe the study sites and the problem in relation to the chemical risks for workers, their families, and neighbors. It aimed to fill the gap of local knowledge on e-waste risks, which seems to be known but not systematically studied or communicated in academic spaces in Argentina. This research question was addressed in Chapter 2.

Hypothesis 1: Chemical risks are assessed by and significant to local authorities but perceived differently by community members. Outcomes:

1.1. Demographics of the community under study, including the context in which they live and work.

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[16] Hinchliffe D. et al. (2020) illustrate this strategy with the case of a successful collaboration between a formal buyer of Printed Circuit Boards (PCBs) and informal collectors in Colombia.

1.2. Chemical risk assessments focused on workers, their families, neighbors, and the surrounding environment.

1.3. Community members' perceptions of risks[17] (including workers, their families, and closest neighbors).

Research question 2: What socio-technological interventions could be implemented to reduce the chemical risks derived from the informal management of e-waste in the context under study? and research question 3: How can the proposed interventions be systematically assessed in order to be successful, accepted, and implemented by stakeholders?

The purpose of these two research questions was to identify, describe, and analyze existing interventions for chemical risk management and propose new interventions to be implemented in the study sites. These questions aimed to fill the gap of contextual risk management measures that understand the perceptions, priorities, and needs of the local e-waste communities. These research questions were addressed in Chapter 3 and Chapter 4.

Hypothesis 2: Some socio-technical interventions could reduce these chemical risks but are unknown to local authorities and community members. Outcomes:

2.1. Information on previous interventions conducted in Argentina related to e-waste risk reduction measures.

2.2. Information on interventions and lessons learned related to risk reduction in this sector in other parts of the world.

2.3. Intervention proposals that include a description of the following:

   a Actors that should be involved during the creation, development, and maintenance of the intervention.

   b Time and resources needed.

   c Necessary arrangements at the community, regulatory, economic, social, cultural, educational, and technological levels.

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[17] It is worth mentioning that the lay population may percept risks differently from the objective risk, which can affect their behavior. Studying their perception supports the design of risk prevention and communication measures (Jensen et al., 2021).

d Influence on the local community's economy; allocation of rights; opportunities and resources; use of energy and materials; and the environment.

e Advantages and disadvantages of each intervention for the environment, the local community, specific subgroups within the community, and citizens in general.

Hypothesis 3: For an e-waste risk management intervention to be successfully accepted and implemented by stakeholders—including community members and governmental representatives—, it should be specific to the local context and assessed in light of its affordability; time, and resources needed; stakeholders involved; economic compensation; productivity; use of energy and materials; capacity building requirements; level of protection of people's health and the environment; reliance on external sources; community members' willingness; allocation of rights, opportunities, and resources. Outcome:

3.1. A methodology that can be followed by regulators and other community development stakeholders when deciding on interventions to minimize chemical risks in the informal e-waste sector.

1.5 Research Approach and Methods

Since the nature of this work is interdisciplinary—i.e., it combines aspects of engineering, environmental health, and social sciences—following a mixed-method approach (Meissner et al., 2011), I applied both qualitative and quantitative data collection and analysis that allowed me to identify convergence and divergence points between the local and global contexts. As The literature from different disciplinary backgrounds and experiences from various countries contribute a knowledge base that is useful in the transition towards sustainable societies, embracing change in our consumption-oriented culture, recognizing the conservation aspect of recycling and valuing the social and environmental service of recyclers. Qualitative data from the fieldwork provided me with contextual insights to understand and interpret risks and interventions from the perspectives of different stakeholders (workers and governmental officials in particular). Quantitative data from the literature was valuable to understand and characterize materials, chemical and physical processes, and the effects on human health and the environment. Furthermore, as Gutberlet, (2008a) explains, “the literature from different disciplinary backgrounds and experiences from various countries contribute a knowledge base that is useful in the transition towards sustainable societies, embracing change in our consumption-oriented culture, recognizing the conservation aspect of recycling and valuing the social and environmental service of recyclers” (p.3).

To describe the research approach and methods, in Figure 1.1 the four key instances for developing this MS thesis are presented, and further details are described below. Details about the case studies and the specific methods are included in Chapters 2 and 3.

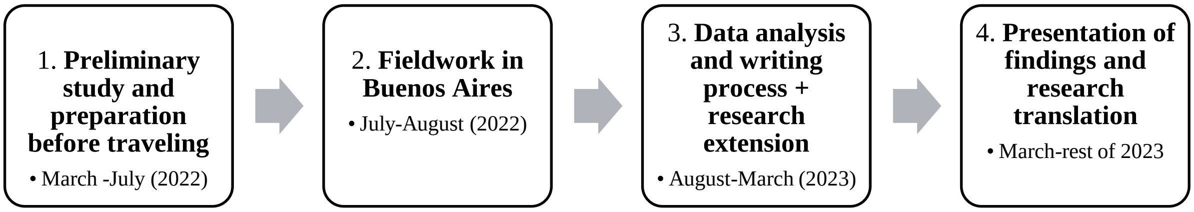

Figure 1.1 Key instances for the development of the thesis.

1.5.1 Preliminary Study and Preparation Before Traveling (March-July 2022)

A series of semi-structured virtual interviews were conducted with local government entities, universities, and civil organization representatives I have already identified and contacted to define the thesis topic. These interviews were designed with the support of the Humanitarian Engineering and Science (HES) faculty and literature on ethnographic methods (Spradley, 2016; Warren & Karner, 2015). During this research, I gathered preliminary information to answer my research questions. In addition, contacting local stakeholders allowed me to select the study sites A and B (protected names, described in Chapter 2), and through snowball sampling, I also identified more people to contact and interview. Throughout this process, I received additional suggestions for my research, including the best participatory methodologies to apply in the field. The interview guides are included as Supplemental Material (Appendix B.1).

Likewise, after learning from the experience of Neitzel et al. (2020) in Thailand[18], I non-officially partnered with two agents of two local governmental entities to build trust and access to the community, the Matanza-Riachuelo Basin Authority (ACUMAR) and the "Argentina Recicla" program at the National Ministry of Social Development. They both took part in the planning of the fieldwork activities.

With a consolidated idea of the riskiest practices applied in the study sites, inspired by intervention projects in other countries and ideas from public sources[19], and following the ESCD criteria (p. 16) and the hierarchy of controls in occupational safety (US NIOSH, 2023), I built one prototype of a simple wire stripper tool and prepared written proposals of other risk management measures (e.g., installation of filtration systems). The methods and the proposals are further detailed in Chapter 3.

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[18] The research team addressed community engagement by building long-term relationships with government organizations, the village leader, and the community team leader. Individual and group meetings allowed all parties to agree on continuing the research project. (Neitzel et al., 2020, p. 74).

[19] Idea Implementer (2022). "How to get copper from a thin wire without firing: a machine for cutting a copper cable" (non-official translation). Access: https://www.youtube.com/watch?v=OUDFFmmmHVw&ab_channel=Ideaimplementer (Accessed: April 3, 2022)

1.5.2 Fieldwork (July-August 2022)

Having obtained previous approval from the Human Subject Review Team at Colorado School of Mines (Appendix B.2 and B.3), the fieldwork activities involved interviews, participatory observations, and two workshops. All subjects gave informed consent for inclusion before participating in the study.

I designed the fieldwork campaign based on an exhaustive literature review, support from HES faculty, and the remote interviews that facilitated the selection of appropriate methods to explain to community members the research's objectives and expectations in an effective and plain language, considering local factors such as the level of formal education, socio-economic status, and culture. I followed some insights from the Rapid Appraisal Procedure (RAP) by Beebe (2008)—a mixed-method approach used to understand complex problems with limited time and resources—and the learnings from the Colorado School of Mines EDNS479 course “Community-Based Research” (J. Smith, 2022). Furthermore, I supported the design of the workshops with examples of participatory methods implemented by Gutberlet et al. (2013), such as brainstorming and active learning, collective mapping, acting, and drawing methods, when they studied occupational health hazards of recycling cooperatives in Brazil.

During the fieldwork campaign, I deepened my understanding of the community's context and dynamics, including power inequalities, needs, concerns, and desires. I also refined the identification of stakeholders, materials, and devices (quantities, conditions), as well as collection and recycling practices (schedule, working conditions, materials needed, costs, treatment of discards), and the characteristics of the value chain (sale price, buyers, fluctuations in prices). To identify and evaluate alternatives to open burning and other harmful practices, I invited users (workers, their families, and closest neighbors) to contribute with their inputs as co-participants of the research. I presented the prototype and the intervention proposals in the workshops, and we discussed the intervention alternatives.

1.5.3 Data Analysis and Writing Process (July- March 2023)

During the data analysis process, I transcribed the interviews and the field notes while analyzing the views of the different stakeholders. Likewise, I reviewed new literature and shared the first findings with the Thesis Committee members, who gave me insights to continue the research. In light of the new findings, I also conducted additional remote interviews with the governmental representatives from the partner organizations.

1.6 Chapters Overview

This thesis consists of three additional chapters and a conclusion. Since the chapters are intended to be published in academic journals, some information previously presented in the Introduction might be duplicated.

Chapter 2 relates to the field of environmental health and is mainly addressed to local government officials in Argentina interested in the occupational and environmental health of communities that work with e-waste or live in environments affected by e-waste management. It is also of interest to researchers focused on carrying out semi-quantitative risk assessments in contexts of high vulnerability, especially in Latin America and the Caribbean. This chapter presents a detailed description of the research methods and the study sites. Combining qualitative data from the study sites with quantitative and qualitative data from the literature, a semi-quantitative occupational risk assessment was performed. The assessment was based on the open burning of copper cables. Observations on take-home exposure are also included[20]. The primary outcome of the risk assessment is its conclusions, which justify the need (or not) to implement interventions to reduce or eliminate risks for each study site. Then, this chapter includes the identification and description of the factors that increase or decrease the risk perception of workers and government representatives involved in decision-making. Chapter 2 concludes with the enumeration of interventions and research recommendations based on the risk assessment and risk perception findings.

Chapter 3 focuses on the analysis of interventions to reduce or eliminate risks related to the open burning of cables, with a particular focus on Site A. It is circumscribed within the fields of occupational health, process, and materials engineering, and business. It is also focused on informing local governments, especially in Buenos Aires, so that they develop contextual interventions in the study sites. E-waste workers from informal and semi-formal sectors are also the targeted audience. The interventions wee proposed based on the NIOSH Hierarchy of Controls (US NIOSH, 2023), analyzed contextually based on qualitative data obtained from interviews, participatory observation, and workshops, and finally evaluated according to the Engineering and Sustainable Community Development criteria (ESDC). The chapter concludes with a description of information gaps and a series of recommendations to continue the investigation at Sites A and B.

Chapter 4 is aimed at mining and engineering professionals and educators. It is a co-authored work with another student from the HES program, Jaime Styer, who studies how construction and demolition waste

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[20] Take-home contamination and exposure occurs when chemicals are transferred by workers from the workplace on their skin, clothing, shoes, and other personal items to their car and home (Newman et al., 2015).

management can empower vulnerable populations. Our research, included in this thesis as a chapter, seeks to install the concept of "urban mining" as an object of study and practice in fields that have traditionally focused on the exploitation of natural resources and not on anthropological resources. In addition, this piece points out the social and environmental benefits related to urban mining globally and in Latin America. To explain these benefits, descriptions of experiences at study sites in Colombia and Argentina wee included. The central claim of this work is that urban mining can be comprehensively understood through participatory community research and sociotechnical analysis through qualitative and quantitative methods. Concluding that this discipline has not yet been firmly installed in mining and engineering programs in the United States, this chapter describes options for integrating urban mining into the curricula through three educational experiences at the Colorado School of Mines in 2022 and 2023. Finally, Chapter 4 concludes with a series of recommendations to continue the research and incorporate urban-mining-related topics in the education of mining and engineering students.

Finally, based on the research questions and hypotheses described in Chapter 1, Chapter 5 summarizes the main results and findings and presents a critical discussion of them. The main objective of this section is to describe the contributions of this MS Thesis to the state of knowledge in the areas of environmental, occupational health, and socio-technical frameworks for interventions related to e-waste management worldwide, particularly in Buenos Aires (Argentina). An explanation of the limitations related to the research's design and implementation was included. I also enumerated my research extension and translation commitments. To conclude, proposals for future areas of research and practice were presented.

CHAPTER 2

CHEMICAL RISKS AND PERCEPTIONS ASSESSMENT IN TWO INFORMAL AND SEMI-FORMAL E-WASTE SITES IN ARGENTINA: A MIXED-METHODS ANALYSIS

2.1 Introduction

2.1.1 Global E-waste Trends, Informality, and Health Impacts

Globally, the increasing demand and supply of electrical and electronic equipment (EEE) are expected to result in an annual generation of 74.7 Mt (million metric tons) of waste by 2030 (Forti et al., 2021). This waste stream, known as e-waste or WEEE, is one of the fastest-growing worldwide. It includes several products, from refrigerators, washing machines, monitors, lamps, fans, and microwaves to IT and telecommunication equipment such as mobile phones and computers. Their components, such as cables and batteries, are also considered part of the e-waste.

During the last decade, e-waste became a topic of high interest for international organizations, governments, and academia, given the economic interest in the recovery of valuable materials found in the EEE (Aldebei & Dombi, 2021), as well as concerns at the environmental level, such as the indiscriminate extraction of raw materials and increasing waste generation. Furthermore, research also began to focus on the health of e-waste workers and other vulnerable groups of people that could be indirectly exposed to hazardous chemicals (World Health Organization, 2021a). EEE contains up to 69 elements from the periodic table (Forti et al., 2021), and nine of the ten priority toxics identified by the World Health Organization (WHO) have been found in e-waste or are released during improper handling, namely, air pollutants, arsenic, asbestos, benzene, cadmium, dioxins, fluoride, lead, and mercury (Pan American Health Organization (PAHO), 2023). Extensive research shows that many of these substances can produce toxic effects on human health, such as carcinogenicity and neurodevelopmental, renal, cardiovascular, reproductive, and pulmonary disorders (ibid.).

The potential for negative health impacts of e-waste management is increased when the materials are inadequately handled, a situation that the academic literature generally relates to informal contexts in marginalized settings. In general, the people who work with e-waste without a regulatory framework that protects them live in vulnerable environments, carry out their activities in risky conditions without personal protection, and are more frequently exposed to dangerous substances than formal workers. Although the informal workers have a relevant role in the circular economy, in some countries informality leaves them outside of the health systems, facing other vulnerabilities such as lower negotiating power with buyers of recycled material, or limited access to financing programs (ILO, 2023).

Risky practices such as manual dismantling, inappropriate shredding, open burning, heating, and acid leaching with effects on the health of adults and children have been reported mainly in Ghana or China (Arain & Neitzel, 2019; Grant et al., 2013; Lundgren et al., 2012; Neitzel et al., 2020; Sepúlveda et al., 2010, 2010; Srigboh et al., 2016; WHO, 2021a; Yohannessen et al., 2019). Furthermore, the literature estimates that e-waste workers lack sufficient information to perceive the risks to which they, their families, and the local environment are exposed (Clinckspoor & Ferraro, 2020; Davey & Walsh, 2019; World Health Organization, 2021). However, the current trend in research is mainly focused on women's and children's health, and many scholars agree that more research and action on occupational safety are needed in both the informal and formal e-waste sector (Arain & Neitzel, 2019; Ceballos & Dong, 2016; Neitzel et al., 2020; NIOSH et al., 2019; Seith et al., 2019; Yohannessen et al., 2019). Furthermore, a WHO 2021 report reads, "waste workers also remain largely invisible in national and global statistics collected on the labor market (WHO, 2021, Executive Summary, p. xviii)."

2.1.2 E-waste in Argentina

Little is known about the informal e-waste sector in Latin America (Yohannessen et al., 2019). The recently published regional report elaborated by Wagner et al. (2022) about the e-waste management in 13 countries[21] is one of the few that has collected updated information on e-waste statistics, legislation, and national management infrastructures. According to this report, Argentina—a country that the ILO also selected as one of the case studies on e-waste decent work (ILO, 2023)—is one of the three countries that produces EEE domestically, the one that produced the largest amount of EEE placed on the market in 2019 (313 kt), and the one generated the most e-waste in 2019 (328 kt) among the 13 countries analyzed.

Argentina is an upper-middle-income country in South America, with a 42 Gini indicator of inequality[22] in 2021, and a population of more than 45 million people (World Bank, 2023). It has been selected as the country of study for this work due to the growing attention to this activity in the country and the recent efforts to produce basic national data on the formal and informal e-waste sector (ILO, 2019; Maffei et al., 2020; Maffei & Burucua, 2020). Even though the sources of information are scarce, some authors have indicated that the number of people dedicated to e-waste management is growing in number, both in the informal and semi-formal sectors (ILO, 2019; Maffei & Burucua, 2020). An ILO 2019 report estimated that

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[21] Argentina, the Plurinational State of Bolivia, Chile, Costa Rica, Ecuador, Guatemala, Honduras, Nicaragua, Panama, Peru, El Salvador, Uruguay, and the Bolivarian Republic of Venezuela.

[22] "Gini index measures the extent to which the distribution of income (or, in some cases, consumption expenditure) among individuals or households within an economy deviates from a perfectly equal distribution. A Gini index of 0 represents perfect equality, while an index of 100 implies perfect inequality." (World Bank, 2023)

there were 34,100 e-waste workers in total, 84% working in informal conditions[23] (ILO, 2019). Currently, it is estimated that 3 to 4% of the total e-waste generated in the country is managed, and the informal sector deals with half of that percentage, according to Maffei & Burucua (2020).

According to our literature review, the few national reports published about risk assessment and management in the e-waste sector are related to the work of an environmental health agency located in Buenos Aires, the Matanza Riachuelo Authority (ACUMAR). In the Matanza-Riachuelo Basin, an area that covers 14 municipalities and has a population of four million, Feiock (2019) has determined that between 2017 and 2019, of 116,545 people surveyed, 4,545 collected and stored e-waste (3,9%), 3,030 (2.6%) burned cables to get the copper, 2,564 (2.2%) melted metals, and (1.6%) 1,864 were engaged in battery recycling. ACUMAR researchers have reported that practices such as the open burning of e-waste—mostly cables, old TVs, and refrigerators—are common, as well as the discharge of lead-acid batteries near public spaces and households (ACUMAR, 2018a, 2021; Comesaña García, 2019; Zavatti et al., 2020). Elevated levels of metals were found in residential soils close to sites of e-waste-related activities, including lead that exceeded the 500-ppm limit allowed in residential soils by –the Decree No. 831/1993 at the national level[24] (Comesaña García, 2019). Some interventions led by ACUMAR, such as biomonitoring and educational activities to promote healthy habits, have been effective in reducing blood lead concentrations below the reference value (5 μg/dL) in children under six years of age. However, they have still not been able to provide workers with any successful e-waste management alternative to eradicate lead pollution (Comesaña García, 2019).

Regarding the risks in the semi-formal sector—a term that we used to include solid waste cooperatives that are transitioning into e-waste management—not much information has been generated. ILO (2019) highlighted that workers in this sector are excluded from the social security system available for formal workers and usually apply less careful processes for the environmental management of e-waste. However, in Buenos Aires, this situation is gradually progressing in the context of the new legislation and alliances between e-waste cooperatives, national social recycling associations (e.g., the Argentine Federation of Cartoneros, Carreros, and Recyclers, FACyR), governmental agencies, and actors from the formal system (ILO, 2019; Maffei et al., 2020; Maffei & Burucua, 2020).

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[23] The informality defined in ILO's report was more comprehensive that the one that was described in the Introduction chapter. It included: workers that did not make contributions to the social security system, self-employed workers, and unpaid workers.

[24] Thresholds for total lead are based on the Canadian Environmental Quality Criteria for Contaminated Sites (Environment Canada, 1991). Agricultural soils: 375 ppm, residential soils: 500 ppm, industrial soils: 1000 ppm.

To overcome the gap between the formal and informal e-waste sectors in Argentina, this paper aims to generate occupational safety data to inform inclusive interventions to reduce chemical risks in informal and semi-formal e-waste management contexts. The research questions are 1) What chemical risks are derived from the informal and semi-formal management of e-waste in the two sites under study? and 2) How do the different stakeholders perceive them?

Following this introduction in Section 1, Section 2 describes the methods used to gather local and international data. Section 3 describes the two study sites in Buenos Aires with sociodemographic details and information about e-waste activities that are unavailable in the existing academic literature. Section 4 includes a semi-quantitative chemical risk assessment associated with the informal management of e-waste, with a particular focus on the treatment of copper cables. Section 5 includes a risk-perception analysis with a focus on workers. Finally, this paper offers a brief conclusion with proposals for further research.

2.2 Methods and Materials

2.2.1 Study Design and Ethics

This is a study with an interdisciplinary nature that uses a mixed-method approach (Meissner et al., 2011). For the development of this research, qualitative methods have been used, including participatory observation, semi-structured interviews, focus groups, and workshops that complemented the literature review. The study design was led by the main author, in consultation with the research team, and the local support of representatives of ACUMAR and the "Argentina Recicla" program of the National Ministry of Social Development. The research protocol was submitted and approved by the Colorado School of Mines Human Subjects Issues Review Team on July 4, 2022 (Appendix B.2).

2.2.2 Literature Review

A scoping review was conducted to characterize available scientific and gray literature, formulate the problem, map existing evidence, and identify data gaps. Forward and backward searching methods were applied starting from comprehensive publications by the WHO (2021), the ILO (2023), and the UN (Forti et al., 2021). Published systematic reviews were also prioritized. Additionally, we used combinations of keywords such as "e-waste," "WEEE," "interventions," "risks," "cables," "lead," "Argentina," and "South America" on Google Scholar and selected the papers based on their relevance for the local context and the subject of study (open burning of e-waste, especially cables). A total of 198 e-waste-related articles were consulted, representing various fields of study, including environmental health, sustainability, waste management, and anthropology. We recognize that a limitation of the scoping review method is related to the authors' subjectivity when deciding the articles' relevance. However, the literature review was only one of the pieces of evidence in this work.

2.2.3 Interviews

From July to November 2022, a total of 15 government representatives, researchers, members of cooperatives, and e-waste programs were interviewed. The meetings lasted approximately an hour and a half and were held virtually. Participants were asked to describe the study sites, e-waste-related practices and dynamics, identify current issues, and provide feedback on risk management intervention strategies. The interview guides are available as Supplementary Material (Appendix B.1).

2.2.4 Observation

Three visits to Site A and two to Site B were carried out in July and August 2022. During the visits to Site A, the main investigator was accompanied by a team of one toxicologist and three social assistants of ACUMAR. An environmental scientist from the Ministry of Social Development led the visits to Site B. The study was complemented with visits to three other e-waste cooperatives in the province of Buenos Aires. Table B.1 in Appendix B.4 briefly describes each of the visits. During the sessions, neither video nor audio recordings were made, except in the workshops, where audio recordings were obtained with the prior permission of the participants. During all visits, photographs of the facilities, workspaces, machinery, devices, and waste were taken with the participants' prior permission, and their identities were protected. The goal of the observation was to understand the different contexts of e-waste communities and their work dynamics, including power distributions, needs, concerns, and desires. Likewise, these visits helped us to find new actors and refine data on materials and equipment (amounts, conditions) as well as collection and treatment practices (schedule, working conditions, necessary materials, costs, resulting waste treatment), and the characteristics of the value chain (sale prices, buyers).

2.2.5 Workshops

Two workshops were held with each group of workers from sites A and B. The group of e-waste workers at Site B (five men) participated in the workshop together with their coordinator (male). At Site A, since the cooperative is not formally managing e-waste, the urban recoverers associated with the cooperative and linked to e-waste activities were invited to participate. The cooperative has approximately 150 workers. In total, 37 workers (17 women, 20 men) and their coordinator (male) participated in the workshop. The activities, led by the main investigator and developed in 2 hours, were:

1. *Initial risk recognition activity.* To understand the level of participants' familiarity with daily and non-daily risks, participants were given an illustration of a domestic scene where two

children were exposed to several hazards of a varied nature, including electrical, chemical, and physical (Figure B.1 in Appendix B.5). They were asked to indicate and describe what they considered risky in that scene. Then, simple definitions of hazard, exposure, and risk were provided.

2. *Risk perception activity.* To understand participants' perception of the risks associated with e-waste processing, images of cables and a cathode-ray tube (CRT) TV before and after being processed through informal practices were shown. On the one hand, the cables, as they are found in appliances, were compared to an open burning scene (Figures B.2 (a) and (b) in Appendix B.5). On the other, a TV was compared to a CRT monitor in pieces (Figures B.3 (a) and (b) in Appendix B.5). The participants were asked to compare the images based on the previously explained concepts of hazard, exposure, and risk.

3. *Presentation of a cable stripper prototype***.** Images of a low-cost handmade cable stripper were shown, and the manufactured prototype was presented (Figure B.4 in Appendix B.5). Participants were asked to provide feedback and compare wire stripping and open burning.

4. *Community mapping (Site A only).* Participants were provided with a printout of a map containing an area close to the cooperative of approximately two hectares. This simple map included street names, landmarks, and cut-and-paste images of a flame (representing open burning), a skein of wires (representing collection points), and a bag of money (representing buyers' location). The groups were asked to identify these sites on the map.

2.2.6 Semi-quantitative Risk Assessment

There are different risk assessment methods, and all have merits and demerits. We followed the US National Research Council's (1983) risk assessment and management paradigm and the indications in the US EPA's *Framework for Human Health Risk Assessment to Inform Decision Making* (EPA, 2014). The lack of systematic monitoring campaigns, data dissemination from both sites, and the need for more robust techniques to describe the exposure limited the possibility of conducting a quantitative chemical risk assessment. However, according to the available evidence, a semi-quantitative study was conducted. In this study, we used a mixed approach (Meissner et al., 2011) by using quantitative and qualitative available data related to the study sites and data from the existing literature. As Jasanoff stated in 1993, “each approach [qualitative and quantitative] captures a different, and only partial, aspect of the complex and multidimensioned reality that our field [risk analysis] tries to apprehend” (Jasanoff, 1993, p.124). Qualitative data from the fieldwork provided contextual insights to understand and interpret risks and interventions from the perspectives of different stakeholders (workers and governmental officials in particular). Quantitative data from the literature was valuable to understand and characterize materials, chemical and physical processes, and the effects on human health and the environment.

2.3 Sites Description

2.3.1 Site A: A Neighborhood with Moderate E-waste Activity

Site A is located in the Matanza-Riachuelo basin and covers an area of approximately 2.11 ha (Figure 2.1). Three small healthcare units and one solid waste cooperative are located in this area. According to the Directorate of Territorial Planning of ACUMAR, the typology of this site is “asentamiento,” meaning that the territory is, for the most part, subdivided into regular plots that make up blocks as a result of a collective land occupation strategy. As shown in Figure 2.1, the closest water body is the Matanza Riachuelo River at 200 meters distance.

Figure 2.1 Site A delimited by purple lines (ACUMAR 2018b).

The most up-to-date published data about this site were collected from a 2018 report (ACUMAR, 2018b). At Site A, there was an estimated population of 1,249 inhabitants in 2018, and 59.7% of the households reported at least one unsatisfied basic need in 2010. In ACUMAR's 2018 survey (n=120 households, 503 inhabitants), 29.2% of households were critically overcrowded, 19.2% did not have access to the water system, and 63.3% did not have septic chambers. Regarding the level of education, 80.6% of people over 25 years have not completed high school. Concerning the employment rates, 33.9% of the people over 18 years did not have any source of income, and 24.9% were informal workers. Of a sample of n=120 households, ACUMAR determined that in nine households (7.5%) cohabitants carried and/or collected scrap metal, in eleven (9.2%) they carried and/or collected cardboard, in five (4.2%) they carried out metal casting, in six (5.0%) they burned cables, and in two (1.7%) they recycled batteries. Nine declared polluting establishments are located in the area: three tanneries, three leather finishing companies, one cloth printing company, and two electroplating workshops. According to ACUMAR, the waste disposal sites are not close enough to directly impact the inhabitants of the neighborhood under study. However, they reported that burning waste is a common practice that causes smoke, which is easily perceived in the area (ACUMAR, 2018b).

2.3.1.1 Description of e-waste management activities at Site A

At Site A, a group of *urban recoverers* was studied, i.e., people not necessarily grouped, who intermittently find and treat EEE or its components in their homes or public spaces and obtain profits based on the sale of the materials, copper being the one of most significant interest to them.

Collection- There is no e-waste collection program at Site A. Therefore, these urban recoverers are key in managing this waste stream. Most of them work for the local solid waste cooperative at Site A. Thus, they usually find e-waste during their trips to nearby areas in search of solid waste they collect in their trucks. This is not their main activity. These workers usually get the EEE in micro-dumps similar to the one in Figure 2.2(a) or, occasionally, by door-to-door collection. The devices and components most frequently found are CRT TVs, lead batteries, refrigerators, and cables as shown in Figure 2.2(b). Some informants highlighted the possibility that some cables and equipment were illegally obtained from the electricity and telecommunication networks, but this information could not be verified.

Estimating the amounts and frequency of collection is complex, given that collection at Site A is circumscribed in a context of complete informality. However, some informants suggested a total of five kilograms of copper recovered per worker per week, depending on the EEE they found. Most of the time, the equipment and components are collected by hand without personal protection.

(a) (b)

Figure 2.2 (a) Micro-dump at Site A (Author). (b) Mixed waste collected by an urban recoverer (Antolini, 2022).

Storage- Some workers store the EEE in their households or on the surrounding streets, as shown in Figure 2.3 (a). Other workers stock the e-waste at the local cooperative (Figure 2.3(b)). Detailed information on storage conditions was not collected, but from what could be observed, the devices are placed outdoors without further protection.

(a) (b)

Figure 2.3 (a) E-waste and other waste streams accumulated on the street at Site A (Author). (b) Mixed waste in the local cooperative located at Site A (Author).

Treatment- A practice described by several informants and confirmed during the workshop and visits is the open burning of cables and other e-waste materials that contain copper (such as refrigerators and CRT TVs). This practice is carried out on the ground or in metal barrels to remove the plastic covering the e-waste and obtain the copper (Figure 2.4 (a)). The process is labor intensive and performed without controlling measures for air emissions. During the visit, it was not possible to demonstrate this practice in real time, but some evidence was obtained during the workshop and site observation (Figure 2.4 (b)). It is also important to note that the recyclers do not tackle the plastics contained in the e-waste and usually discard them.

(a) (b)

Figure 2.4 (a) Open burning of cables in Buenos Aires (ACUMAR, 2022). (b) Ashes on the ground after suspected open burning at Site A (Author).

Figure 2.5 shows that the 37 participants evidenced six open burning areas on approximately two ha. During the workshop, questions about other e-waste treatment processes were not included. However, some interviewees mentioned practices such as the manual crushing of CRT TVs with hammers and discharging lead-acid batteries on the ground. As can be seen, a large number of points are located close to the riverbank area. Some participants stated that it is due to complaints from neighbors about the smoke generated by the open burning. However, burning points continue to be frequent in the vicinity of homes and public sites, as indicated by one of the interviewees.

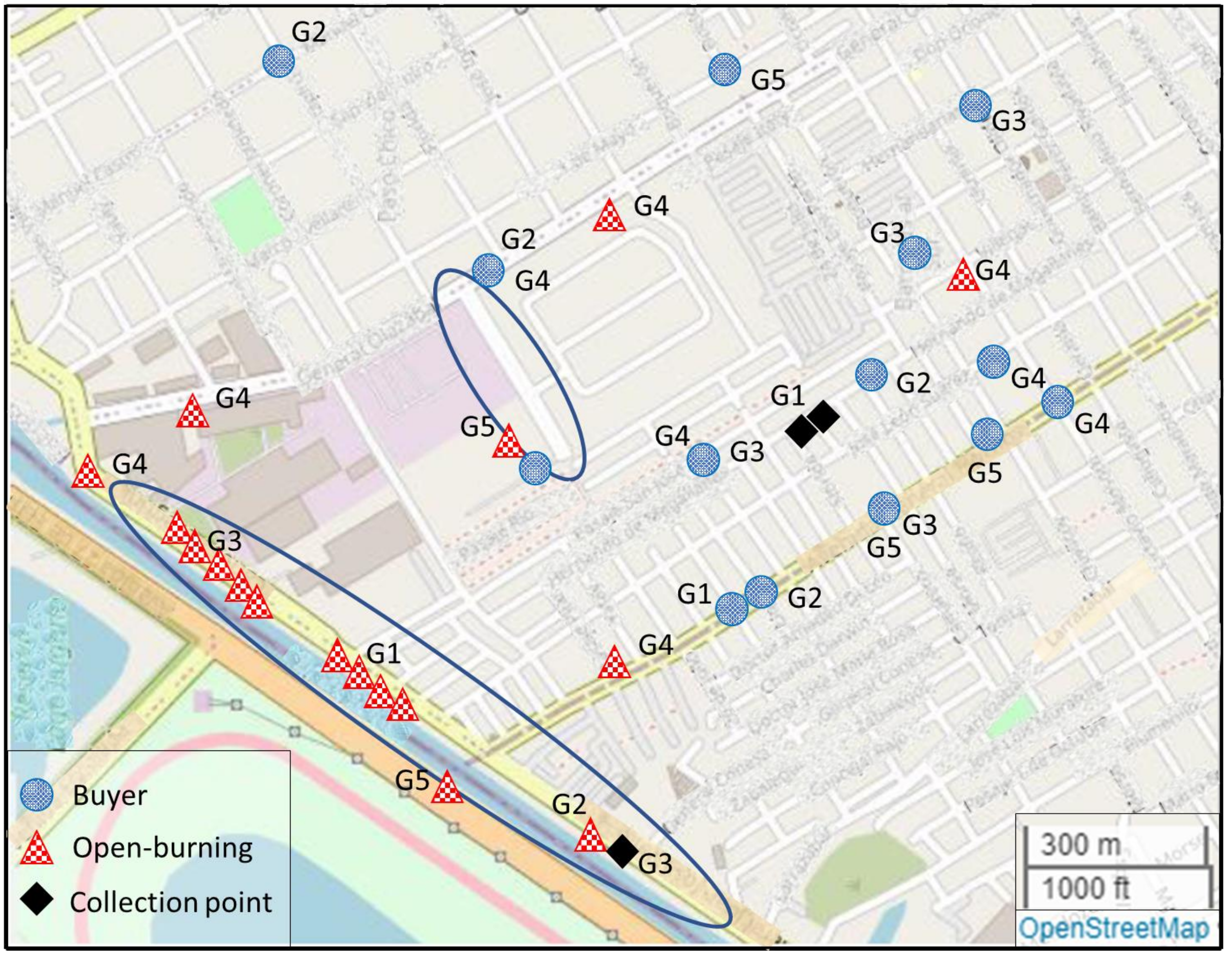


Figure 2.5 Map with the responses of the five groups (G1-G5) that participated in the workshop at Site A. Note 1: G5 marked zones instead of points (blue ovals). Note 2: To protect the confidentiality of participants, references to streets and places of interest have been hidden.

Market- During the workshop, the participants identified at least 14 points of purchase of metals (Figure 2.5). Most of these sites are small informal businesses and receive different types of metals such as lead, copper, aluminum, and components such as "bocha" (i.e., a refrigerator compressor), and batteries (Figure 2.6). Regarding the prices and conditions of sale, although we had no contact with the intermediaries, the urban recoverers have reported prices between 1,500 and 1,800 Argentine pesos per kilogram (equivalent to 2.9 to 3.5% of a basic salary for the time of the workshop according to Resolution MTEySS N° 11/2022) for the copper of burned cables and stripped cables, respectively.

Figure 2.6 Sign of a small metal buyer shop at Site A that reads “I buy copper, bronze, aluminum, profiles, lead, refrigerator compressor, battery” (translated from Spanish).

2.3.2 Site B: Solid Waste Cooperative Transitioning into E-waste

The unit of analysis for Site B is not an entire neighborhood but a solid waste cooperative transitioning into e-waste activities. This cooperative is located in the area of the Matanza Riachuelo basin, in an industrial complex, as shown in Figure 2.7. This site is next to a water body and an ecological park.

At this site, we studied a group of e-waste cooperativists. They progressively started dealing with this waste stream in November 2021. In February 2022, they started formalizing their activity as “refunctioning managers,” according to the Resolution OPDS N° 269/19 (2019) of Buenos Aires.

Figure 2.7 Site B delimited by red lines. (Source: Google Maps. 2023 CNES / Airbus, Maxar Technologies 2023)

The e-waste workers and their coordinator come from different neighborhoods located nearby. They are six men from 25 to 63 years old. Their level of formal education varies from partial primary school to completion of community college education. No additional demographic data were obtained from this group. However, we can describe the worst-case scenario from one of their neighborhoods that, according to ACUMAR (2019), has the greatest conditions of vulnerability in Argentina. In 2019, this neighborhood had a high proportion of households with critical overcrowding (8.7%), a high proportion of households without access to water services for consumption (34.9%), sewage drainage (43.0%), and gas (99.9%). This neighborhood site, as well as Site B, is located in a highly industrialized area. ACUMAR (2019) indicated that their interviewees pointed out that they frequently observe dust, smoke, and strong odors coming from the burning of cables and general waste, a nearby petrochemical complex and waste treatment plant.

2.3.2.1 Description of E-waste Management Activities at Site B

Collection- This cooperative does not offer an e-waste collection service yet. The workers usually receive the EEE from public institutions (e.g., ministries, hospitals) voluntary collection programs, and businesses nearby. They also receive the EEE that are found during the segregation of the solid waste fraction. The amount they receive fluctuates and largely depends on the available storage space. The most common EEE are keyboards, monitors (CRTs and LEDs), computers, and lamps. They did not accept printers because they considered them more hazardous and difficult to treat.

Storage- The e-waste sector is distributed across an interior space inside a workshop that is shared with the plastic bags sector (Figures 2.8.(a) and (b)) and an exterior space, which includes an open roofed area where solid waste is also stored (Figure 2.9). Most of the components and materials are classified and ordered by type. There are special containers for hazardous waste (e.g., lamps with Hg content) because they cannot be managed in the cooperative. The container was adjacent to a small table where they usually serve food. No ventilation or extraction systems were identified.

(a) (b)

Figure 2.8 E-waste sector at Site B (indoors) (Author).

Figure 2.9 E-waste sector at Site B (outdoors) (Author).

Treatment- Work tasks mainly consist of refunctioning EEE or disassembling and then classifying materials of those EEE that cannot be repaired. There is a specific designated area with tools for these activities. No ventilation or extraction systems were identified. Regarding hygiene and safety measures, during our visits, the workers wore special clothes and had gloves and helmets available. Some change their clothes after working and wash them at home separately from other, non-work laundry. They do not have showers in the cooperative. To our understanding, they do not apply wet cleaning methods in the workplace. Regarding risky practices, through the interviews and workshops, we were informed that a great burning of cables was carried out at the end of each year to earn extra income before the holidays. They obtained approximately 600 kilograms of copper just from this one event. It has also been reported that to reduce the large volume of stored CRTs, the workers manually grind the devices with a sledgehammer outdoors, looking downwind while wearing an elastomeric half facepiece respirator.

Market- As this cooperative recently started in the business, they do not have a list of purchasers. Regarding the copper market, from our interactions, it was stated that most buyers are informal.

2.4 Semi-quantitative Chemical Risk Assessment: Open Burning of Copper Cables

This section summarizes the findings from the scientific literature, the local environmental health agency reports, and our own research that allowed the characterization of chemical risks to justify the choice of risk management measures.

2.4.1 Problem Formulation

According to the PAHO (2023), informal e-waste management can represent three risk scenarios: i) occupational, which occurs at the site where the EEE are managed; ii) domestic, when a house is close to the recycling area; and iii) environmental when chemical releases are produced and contaminate surrounding areas. This multiplicity of scenarios and the heterogeneity in the composition of the devices make the risk assessment process challenging (Arain & Neitzel, 2019). Furthermore, it is important to note that i) and ii) can be the same scenario in some neighborhoods.

This risk assessment is based primarily on the findings of ACUMAR that helped us to narrow down the problem. ACUMAR systematically monitors individual and community cases of lead exposure, as part of the so-called “Comprehensive Environmental Health Assessments in Risk Areas” (“Evaluaciones Integrales de Salud Ambiental en Áreas de Riesgo” or EISAAR, in Spanish) (ACUMAR, 2018a, 2021; Feiock, 2019). The EISAAR methodology comprises ten stages illustrated in Figure A.1 (Appendix A). It has been designed applying the Methodology for the Identification, Evaluation, and Attention of Health Risks in Communities of Contaminated People developed by the Collaborating Center for Children's Environmental Health of the PAHO and the WHO. With the data obtained through the EISAAR in different sites, they determined that the open burning of e-waste is risky and closely related to lead exposure. In the literature, open cable burning is also considered one of the most hazardous activities, along with the cooking of circuit boards and acid baths (Sepúlveda et al., 2010; Song & Li, 2014; WHO, 2021). E-waste burners most commonly have the highest concentrations of contaminants, according to some scholars (Srigboh et al., 2016), followed by intermediaries, dismantlers, collectors, scrap dealers, and repairers. Waste burners also had the highest PM exposure among e-waste workers in a study by Kwarteng et al. (2022). Among all e-waste recycling processes, open burning and acid leaching release the largest amounts of dioxins (Luo et al., 2021).

Based on the information gathered through the EISAAR process and the interviews and observations made during this investigation, our assessment focuses on the occupational scenario, specifically the open burning of copper cables. In their systematic review, Arain & Neitzel (2019) found that several studies showed higher levels of certain metals in occupational exposures compared to non-occupational exposures, the last still higher than the control or other groups of reference. In this regard, the main population under study is workers over 18 years of age. However, some considerations about vulnerable groups, such as women and children indirectly exposed to this activity, are also included in our work since more data has been generated for these groups, and negative effects of their exposure have been extensively reported (Newman et al., 2015; WHO, 2021). In any case, the data for e-waste workers is usable as the worst-case exposure scenario because of their higher direct exposure, according to Frazzoli et al. (2010). This assumption is also supported by Ceballos & Dong (2016), who, after a comprehensive review of the literature, concluded that formal e-waste workers' exposures are often above occupational guidelines for metals and higher than reference group levels for brominated flame-retardants.

2.4.2 A Conceptual Model for the Study of Open Burning of E-waste at Site A and Site B

Figure 2.10 describes the comprehensive conceptual model that includes the linkages between the potential risky activities and adverse human health effects, the stressors, exposure pathways, and exposed populations. Indoor air is only considered for site A since, in some cases, the open burning is adjacent to the households, and the combustion products can easily enter indoors. This situation is not replicated at Site B since the open burning is conducted far from the workshop. Food is another media that is only associated with Site A since it was reported that three of 120 households have small farms (ACUMAR, 2018b). Site B is only a working facility, and no food is produced there. As shown in Figure 2.5, the open burning is close to a water body at Site A, while the activity at Site B is not carried out in the vicinity of Site B, according to our interviews.

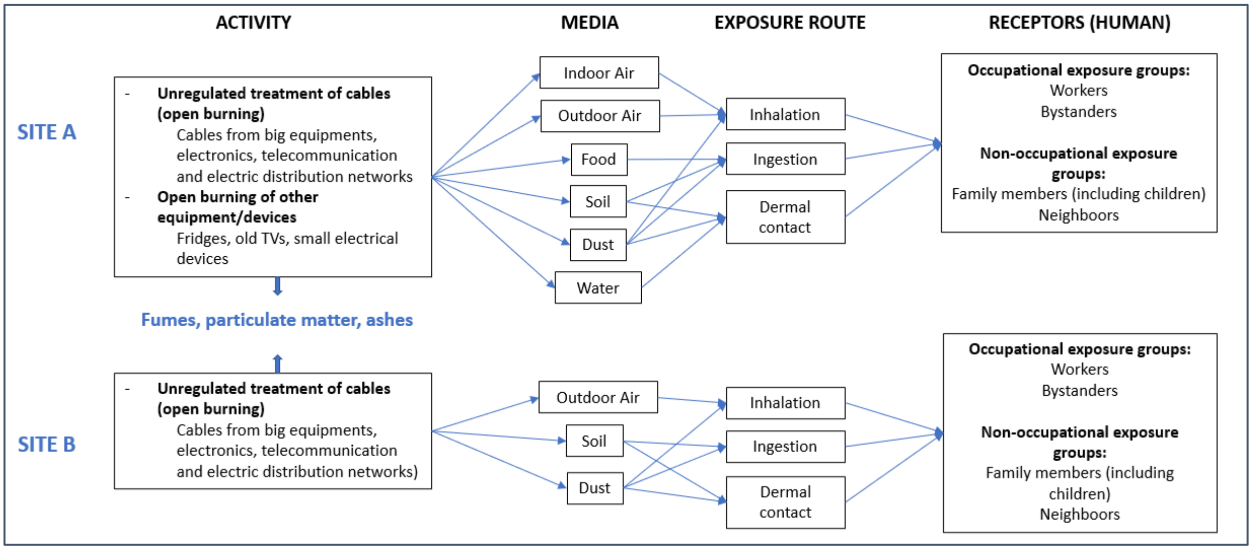


Figure 2.10 The conceptual model for the study of open burning of copper cables (Author).

2.4.2.1 Scenarios Presented in the Conceptual Model but Not Considered in This Assessment

As indicated above, beyond the direct occupational exposure in workplaces and homes, communities living in e-waste sites are also exposed to pollutants from the burning of materials via polluted air, water, soil, and local food (WHO, 2021). These scenarios are well studied globally but are out of the scope of this evaluation.

This study focused on the open burning of cables not only because these components are easy to find and handle, and are one of the main sources of copper, but also because of the higher potential human health in comparison with other components, such as circuit printed boards (Cesaro et al., 2019). However, other EEE and e-waste treatment activities (collection, storage, dismantling, and transport) contribute to the exposure of workers and the general population at the study sites (Tsydenova & Bengtsson, 2011). For example, collecting and storing lead batteries could release toxic leachates that can expose the population to heavy metals. The management of CRTs—which can potentially break if stored in poor conditions—can lead to the generation of particulate matter and the emission of hazardous gases, including phosphorus. Likewise, the manual smashing of CRTs was identified on both study sites, an activity that could generate leachates and particulate matter, and potentially, major releases of lead. Furthermore, other relevant sources of copper that the local authority has identified in open burning spots at Site A include refrigerators, circuit boards, and TVs. All these activities may also carry risks and should be considered for future assessments and risk intervention measures. To support future work, Table A.2 (Appendix A) briefly describes the main chemical risks identified at Site A and Site B in relation to general e-waste management. In Table A.3 (Appendix A), we provide details about other EEE burned at Site A that should be the subject of future risk assessment.

2.4.2.2 Vulnerable Groups

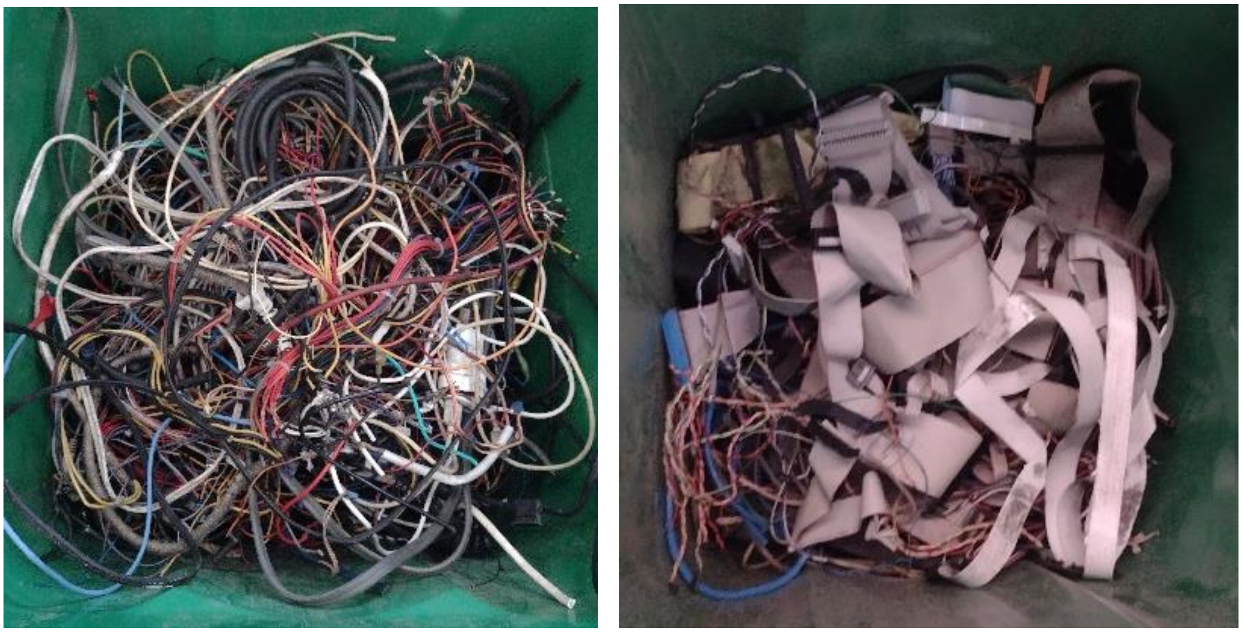
Although they are not the central subjects of this evaluation, women who are pregnant, nursing, or of childbearing age, as well as children, are considered vulnerable populations (PAHO, 2023; WHO, 2021b). Both groups can be exposed to e-waste pollutants in diverse ways. For example, workers at e-waste sites can carry home contaminated clothes and materials that expose cohabitating women and children to the chemicals (Newman et al., 2015; Sepúlveda et al., 2010). According to our visits and interviews, women are usually in charge of domestic chores, such as general cleaning and clothes washing, tasks that increase their exposure to dust contaminated with e-waste toxic chemicals. They also have greater susceptibility related to their metabolism, hormonal cycles, immune, reproductive, and skeletal systems (PAHO, 2023). Children are at greater risk from inhalation because of their higher breathing rate and from dermal contact and ingestion because they are likely to put their hands, objects, and soil in their mouths, known as pica–

compulsive ingestion (Lundgren et al., 2012). Furthermore, children are at increased risk because their various biological systems are still developing. They also usually play outdoors in places close to open burning sites, according to the interviews and observations related to Site A. These characteristics put them at the highest risk.

2.4.3 Hazards Identification and Characterization

The risk assessment depends on the types of toxicants, which are determined by the EEE being treated (Neitzel et al., 2020; Heacock et al., 2016; Srigboh et al., 2016). The characterization of the hazards associated with the open burning of cables depends on the composition of the cables, the fuel (ethanol being the most used), and the substances generated from the combustion. During this research, samples of the cables under treatment were not taken, but stocks were photographed, and their origins were evaluated.

The cables from Site A (Figure 2.2(b)), as well as Site B (Figures 2.11(a) and (b)), come from a diverse range of EEE, from temperature exchange equipment, screens, monitors, lamps, fans, microwaves, to IT and telecommunication equipment (e.g., mobile phones, computers), and even abandoned cars. However, as Cesaro et al. (2019) pointed out, cables' structure is primarily the same and includes a conductive metal core for data and electricity transmission (copper), an insulating cover, and a protection layer with flame-retardants. These authors also provided a comprehensive summary of the composition of several types of copper cables (Cesaro et al., 2019, p. 11047).



(a) (b)

Figure 2.11 (a) Sample of cables at Site B categorized as “Cables” (Author). (b) Sample of cables at Site B categorized as “Computer cables” (Author).

While in their summary there is no mention about lead in cables, some other sources report that they may contain stabilizers, such as Pb, encountered in plasticized polyvinyl chloride (PVC) (Turner & Filella, 2021). Flame retardants, such as tricresyl phosphate (TCP), decabromodiphenyl ethane (DBDPE), 2-ethylhexyl 2,3,4,5tetrabromobenzoate (EH-TBB), bis(2-ethylhexyl), and tetrabromophthalate (BEH-TEBP) –less commonly used–have also been found in cables (NIOSH et al., 2019).

Another potential source of cables was identified, namely the electric power network[25]. These cables (Figure 2.12) contain insulation materials such as vulcanized india rubber (natural rubber mixed mainly with sulfur), synthetic rubber (butyl rubber, silicone rubber, neoprene, and styrene rubber, all made by synthetic elastomeric compounds), polyvinyl chloride (PVC), varnished cambric, vulcanized bitumen, or paper insulation impregnated in oil. Modern insulation materials are polyethylene, polypropylene, polyurethane, polyester elastomer, mylicon, and cellular fluoropolymer fluoroelastomer. The most common conductors are copper, aluminum, tin-plated copper, silver-coated copper, and nickel-coated copper. The sheaths and armor contain lead or steel (Murty, 2017).

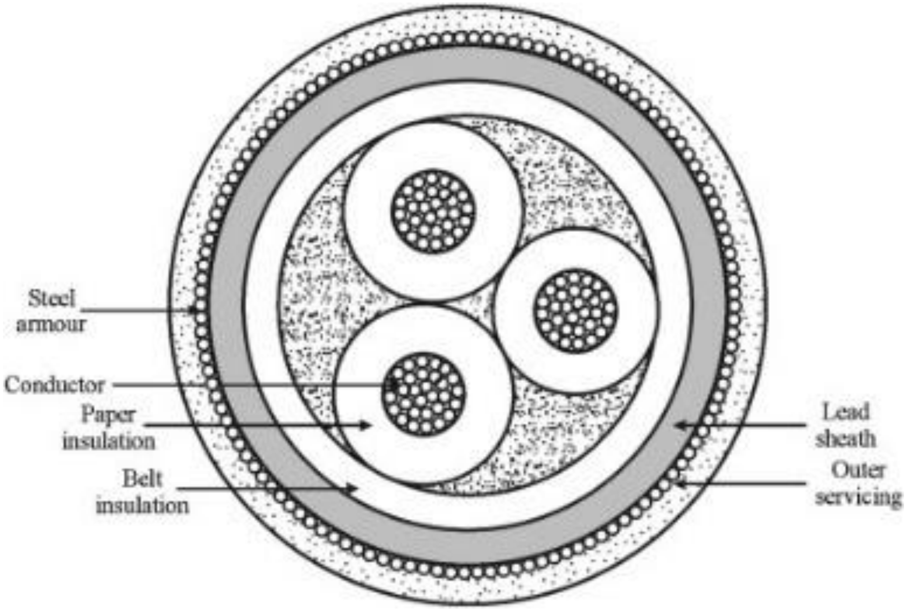


Figure 2.12 Three-core belted cable (Murty, P. S. R., 2017).

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[25] Some informants have indicated that public infrastructure, such as power cables and transformers, have been vandalized in the area of Site A. This situation is mentioned in a national report (Centro Regional Basilea para América del Sur & Ministerio de Ambiente y Desarrollo Sustentable de Argentina, 2018)and has also been reported in other countries (R. J. Grant & Oteng-Ababio, 2016)

As a result of the combustion process, some substances change their state, while others are generated as combustion products. Table 2.1 summarizes the chemical compounds released during the burning of copper cables, assuming that they are typically burned mixed.

Table 2.1 Main combustion products released during the open burning of cables, their effects, and reference doses. PEL: Permissible Exposure Limits. PMx: Particulate Matter (x: diameter in microns). TEQ: Toxic Equivalency Values. TDI: Tolerable Daily Intake. TWA: Time-Weighted Average.

Combustion products	Main toxic effects on humans	Reference dose or guidance value	Additional comments
Heavy metals that are released into the environment during the burning process (Frazzoli et al., 2010; NIOSH et al., 2019; OSHA Standard 1910.1025 - Lead, 2020; Stockholm Convention, 2004; Turner & Filella, 2021; US Agency for Toxic Substances and Disease Registry, 2020; WHO/JECFA, 2011; WHO, 2021a)			
Lead	Neurodevelopmental Renal Cardiovascular (hypertension) Reproductive Probably carcinogenic to humans	Food: Not possible to establish a new health protective provisional tolerable weekly intake (previous: 0.025 mg/kg bw, WHO/JEFCA) Air: OSHA's PEL for airborne exposure: 50 µg/m3 (8-hour TWA). California Department of Public Health: 0.5-2.1 µg/m3 (8-hour TWA). Air (chronic inhalation): Screening Risk Assessments: 0.15 µg/m3 (EPA, 2021, Resolución ACUMAR No 2/2007) Soil: 140 ppm (Canadian guidelines)	The current consensus in the scientific community is that there is no safe level of exposure to lead, particularly for young children. The current European RoHS limit for Pb in any electrical and electronic equipment component is 1000mg/kg.
Persistent organic pollutants (Frazzoli et al., 2010; Qin et al., 2019; Stockholm Convention, 2004; WHO, 2021a)			
Polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs) from trace oils and the presence of chlorine from plastics in the cables.	Endocrine disruption Cancer Neurobehavioural	TDI: range of 1–4 pg TEQ/kg body wt/day) (WHO, 1998)	The incomplete incineration of chlorinated plastics causes PCDD/PCDF generation. Copper is the most efficient metal to catalyze PCDD /PCDF formation.

Table 2.1 Continued

Polycyclic Aromatic Hydrocarbons (PAH) are produced unintentionally due to pyrolysis or incomplete combustion of organic matter from anthropogenic and natural sources (Asamoah et al., 2019; Frazzoli et al., 2010; Kwarteng et al., 2022; Stockholm Convention, 2004; F. Wang et al., 2012; Y. Wang et al., 2016; WHO, 2021a)			
Acenaphthene, acenaphthylene, anthracene, phenanthrene, fluorene, fluoranthene, benz[a]anthracene, chrysene, naphthalene, pyrene, benzo[a]pyrene, benzo [b]fluoranthene benzo[k]fluoranthene, dibenz[a,h]anthracene benzo[g,h,i]perylene indeno[1,2,3-cd]pyrene	Cancer Respiratory (chronic nasal inflammation, olfactory epithelial metaplasia, and respiratory epithelial adenoma)	There is no acceptable daily intake guideline for PAHs in human milk.	Naphthalene and phenanthrene were the most abundant PAHs measured by Kwarteng (2022).
Others (Stockholm Convention, 2004; WHO, 2021b)			
Particulate matter	Cardiovascular Respiratory Neurological Cancer	AIR: PM_{10}: 45 µg/m3 (24-hour); 15 µg/m3 (annual) $PM_{2.5}$: 15 µg/m3 (24-hour); 5 µg/m3 (annual)	-

It is known that carbon monoxide, sulfur dioxide, and hydrogen chloride are also generated as combustion products (Stockholm Convention, 2004). However, these chemicals are out of the scope of this assessment since existing e-waste literature has not focused on them. It is worth mentioning that they all are pollutants of relevance and that there is most robust evidence for public health concerns, according to the WHO (2023).

2.4.4 Exposure Assessment

2.4.4.1 Levels of Toxicants at The Study Sites

By September 2018, 1,000 determinations of lead in the soil had been carried out in more than 20 neighborhoods of 13 municipalities of the Matanza-Riachuelo basin (ACUMAR, 2018a). For lead measurements in soil, this local governmental entity uses a Portable Direct Reading X-Ray Fluorescence Spectrometry (XRF) Analyzer. In the exploratory stage, the analysis is conducted on the first two superficial centimeters of the soil, and then, if further exploration is needed, they take deeper measurements (ACUMAR, Environmental Health Strategy, 2019).

Regarding Site A, ACUMAR confirmed high lead levels in the soil of open burning sites. These levels often exceeded the 500-ppm specified for residential soils in the national regulation on hazardous waste under Decree No. 831/93 (1993) (Comesaña García, 2019). However, the data from the monitoring campaigns are not systematically published, so it is not possible to have quantitative data or statistical analysis of these values. Hence, it is not possible to determine a site-specific average value of lead concentration in soil to be used in a risk assessment. There are no published air pollutant measurements at Site A since ACUMAR has not conducted air monitoring campaigns.

In the case of Site B, to our knowledge, no measurements of pollutant levels have been taken in the immediate vicinity of the place where the burning activity takes place in any of the environmental matrices. However, ACUMAR carries out continuous air quality monitoring of nitrous oxides, ozone, particular matter (PM_{10}, $PM_{2.5}$), sulfur dioxide, and carbon monoxide in one station located less than one kilometer from the cooperative. These data could serve as valuable background information for comparison if future air measurements are conducted at study Site B.

2.4.4.2 Biomonitoring and Health Perception

At Site A, ACUMAR uses lead as the main biomarker for e-waste exposure due to its persistence and traceability in the environment and the human organism and because it is also an indirect indicator of possible exposures to other metals (ACUMAR, 2021)[26]. The literature also supports these observations. As Arain & Neitzel (2019) indicate, “Given its damaging health impacts on current and future generations, its environmental persistence, and the evidence of exposure shown in this review, Pb would appear to be the metal of primary concern in e-waste recycling” (p. 18). Following the previously described ACUMAR's EISAAR methodology, when health professionals consider it appropriate, biological samples are taken to obtain the lead dosage in venous or capillary blood with a LeadCare® Portable Analyzer. They referred the most relevant cases to the laboratories of their network (ACUMAR, 2018a). ACUMAR uses the value of 5 ug/dl, suggested by the Ministry of Health of Argentina, as a determining factor of high exposure (ACUMAR, 2018b). This guidance value is also accepted in the literature for community exposure (Newman et al., 2015; NIOSH et al., 2019). Occupational limits are typically higher, but in 2015, the US NIOSH defined elevated Blood Lead Level (PbB) as PbB ≥5 μg/dL (US ATSDR, 2020).

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[26] Other contributors to lead levels might include paints and gasoline. However, in Argentina this substance and its compounds are restricted in both products by the Resolution No. 7/2009 by the Ministry of Health and Disposition No. 285/98, respectively.

Regarding site A, between 2013 and 2012, of a total of 763 monitored individuals (0 to 19 years), the levels of lead in blood exceeded the reference in 312 people (40.9%) (ACUMAR, 2018b). Updated data about levels of lead in blood at Site A have yet to be published by the local authorities. However, interviewees confirmed that ACUMAR is still conducting biomonitoring.

In 2018, a group of 503 inhabitants from Site A were asked about their perception of health (ACUMAR, 2018b). The most frequent health problems were cough or difficulty breathing (6.4%), parasites (5.6%), and diarrhea (5.4%). Seven people (1.4%) reported lead poisoning as a health problem that ACUMAR linked with exposure related to e-waste treatment. Of a group of 250 adults (over 18 years old), 8.8% declared high blood pressure or hypertension as the primary health problem.

At site B no biomonitoring was in place in the context of occupational health surveillance because when this research took place, cooperatives were not included in the formal labor regulatory framework under Law N° 24.557 on Occupational Risks (1995).The interviewees confirmed that ACUMAR conducted a biomonitoring campaign in late 2022. This campaign included all the workers in the cooperative at this site—the ones working with e-waste and the ones working with solid waste— however, the data has not been published yet.

2.4.4.3 Data Gaps in Exposure Assessment for the Occupational Scenario

As previously stated, this is a preliminary semi-quantitative study since the data generated is not sufficient for quantitative analysis. For more specific results in the local context, data generation should be performed through a rigorous procedure, for example, by conducting surveys and additional, multi-media environmental measurements (Nieuwenhuijsen, 2005; WHO, 2021a). Using surveys and statistical techniques can improve the evaluation of links between exposure and elevated levels in biomarkers (Arain & Neitzel, 2019).

Based on the information gathered through the interviews, observation, workshops, and literature review, Table A.4 (Appendix A) contains proposed exposure descriptors that can guide future quantitative work. It is relevant for the risk assessors in charge of future evaluations to consider other factors that affect exposure. They can include the quantity and type of waste burnt, proximity to the fire, duration of work near the fire, and prevailing wind speed and direction (Bungadaeng et al., 2019; Kwarteng et al., 2020, 2022; Laskaris et al., 2019). Kwarteng et al. (2020) found that the highest PM concentrations at the e-waste site and elsewhere in the community occurred in the evening due to increasing atmospheric stability, continued burning, and other emissions. Workers' ages, residence time, sex, and socioeconomic status are also important factors to consider (Shkembi et al., 2021).

2.4.4.4 Cumulative Exposure and Syndemic Exposure

As in many other e-waste contexts, in both sites, there are contributions of pollutants from external sources, including traffic, biomass combustion, pesticides, and industrial emissions, that also deserve attention (Kwarteng et al., 2022). Furthermore, these workers are generally associated with one or more additional jobs, such as solid waste recycling, which expose them to other risks. Additionally, as described, both groups at Site A and B live in highly vulnerable areas, and other threats might become a health risk. For example, the EISAAR, (ACUMAR, 2018b) has identified the following environmental problems at Site A:

- The groundwater is not suitable for consumption because there is an excess of ammoniacal nitrogen, and the surface water has a substantial excess of fecal coliforms. Since there is a lack of access to drinking water inside the home, it is provided by municipal trucks.
- There is a lack of access to sewers (0% of households surveyed have a connection to a sewer network).
- Many inhabitants have difficulties accessing public health services.
- The area was formerly a dump, so most of the households are located on filled land (91.7%) with potentially hazardous waste disposal.
- There are odors due to the proximity of the tanneries declared polluting agents by ACUMAR. Although no chimneys are observed, the most significant risk in tanneries is groundwater contamination, mainly with chromium.
- The soil is contaminated by chromium from some of the declared industrial facilities nearby that were listed in section 2.3.1.

Considerations about syndemic health impacts, i.e., the potential of one health condition to aggravate another, are also relevant for this assessment, as are possible synergistic health impacts from mixed exposures (PAHO, 2023). For a comprehensive analysis, individual population problems, such as poor diet, lack of hygiene and sanitation, parasitic diseases, and anemia, should also be considered.

2.4.5 Risk Characterization

Table 2.2 (pages 45-46) compiles some risk characterization results from a series of studies related to informal e-waste sites worldwide. This table is not comprehensive, and it is intended to illustrate the many factors and outcomes that are linked to a risk assessment.

Table 2.2 Not comprehensive literature review of risk characterization for the burning of e-waste (occupational-related scenarios). AT: Average Duration of Exposure. BW: Body Weight. ED = Exposure Duration. EDI: Estimated Daily Intake. EF: Exposure Frequency. ET: Exposure Time. FR: Retention Factor. FA: Absorption Factor. IR: Intake Rate. IURi: Inhalation Unit Risk Factor. HQs: Hazard Quotients. LOD= Limit of Detection. TEQ: Toxic Equivalent Value.

Group under study	Chemical	Media and levels of contaminants reported	Exposure assessment	Evidence of risk determination	Qualitative risk characterization for the study sites	Reference & method of risk characterization
Mothers (exposure) and Infants (exposure & risk)	PAHs	Breast milk: ΣPAH= <LOD-15,936.6 ng/g lipid wt. PAH_{mean}=1105.63 ng/g lipid wt. Naphthalene (77.4% of total PAHs) mean concentration= 1026.52 ng/g lipid wt (highest).	Women residing or working around Ghana's largest e-waste recycling and dump site. Activities: dismantling, recycling. Benzo[a]pyrene as indicator for human exposure. IR= 700 g milk/day; ED= 1 year; BW= 5kg; EF= 350 days/year; AT= 2 years.	Risk assessment for carcinogenicity and mutagenicity on infants were 1.1×10^{-5} and 1.9×10^{-5}, respectively[27].	The result of carcinogenicity and mutagenicity assessment on PAHs in human breast milk gave a negligible risk.	Asamoah et al. (2019) Methods: TEF by USEPA (2002) and MEF by Durant et al. (1999, 1996) Exposure and intake assumptions: USEPA (1991).
	PCDDs and PCDFs	Breast milk: total TEQ PCDDs (4.71 pg/g lipid), PCDFs (4.63 pg/g lipid), and PCDD/DFs (9.68 pg/g lipid)	Large, domestic e-waste disposal and recycling site for 40 years. Milk per day in mL=700 mL; Milk lipid wet weight =4%; PCDD/DFs TEQ in breast milk= (9.68 pg/g lipid); Infant weight at 6 months= 5kg	EDI level (54.21 pg TEQ/kg body wt/day) was 13.5 times higher than the tolerable daily intake mentioned by the WHO (1–4 pg TEQ/kg body wt/day)	Higher concentration of dioxin exposure in the e-waste recycling site and higher health risks for the mothers and infants when compared with the reference site.	Luo et al. (2021) Method: not informed TEQ: Van Leeuwen et al., (2000).

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[27] This means that approximately one out of 100,000 and two out of 100,000 infants may have cancer and other non-cancer related adverse diseases such as pulmonary diseases or low IQ during their lifetime due to taking carcinogenic PAHs in breast milk.

Table 2.2 Continued

Group under study	Chemical	Media and levels of contaminants reported	Exposure assessment	Evidence of risk determination	Qualitative risk characterization for the study sites	Reference & method of risk characterization
Infants (exposure & risk)	PCDDs and PCDFs	Soil: Average ΣTEQ= 29.76 pg TEQ m^{-3}	Formal e-waste disposal area. Average soil ingestion rate= 30 mg/day; Average body weight= 40 kg (12-year-old child). TDI values recommended by the WHO for PCDD/Fs (1–4 pg TEQ/kg bw/day)	TEQ concentration in soil/dust exceeding 1333–5333 pg TEQ/g can be considered a high exposure risk for children. The ΣTEQs in the soil samples were far below the threshold.	Human exposure to these contaminants at the e-waste disposal area was mainly below the proposed limits, indicating a low risk to children.	Zhou et al. (2021) Exposure descriptors: Tue et al. (2019)
Workers (exposure & risk)	PAHs	Air: Median ΣPAH concentration= 88.4 ng/m^3 PAH levels span an enormous range, e.g., 0.01–110,000 ng/m^3 in a review of 44 African studies.	Dismantling, sorting, shredding, and open burning of electrical cables, circuit boards, and Styrofoam. FR= 1, FA= 1, ED= 40 years, and AT= 350,400 hr (40 years). ET= 9.4 hr/day, EF= 307 day/years (survey averages).	For several PAHs, lifetime excess cancer risks exceeded the 10^{-6} criterion. Most studies report risk levels in the 10^{-6} to 10^{-5} range. HQs for naphthalene and benzo(a)pyrene were below 1.	Lifetime excess cancer risks for several PAHs were in the 10^{-4}-10^{-6} range. Evidence suggests a minimal likelihood of an adverse non-cancer health effect.	Kwarteng et al. (2022) PAH levels: Munyeza et al. (2019). IURs taken from USEPA (2017). Method: U. S. Environmental Protection Agency guidelines (USEPA, 2009).
	PM	Air: $PM_{2.5}$ and PM_{10} concentrations 99 ± 56 and 218 ± 158 µg/m^3 (median ± interquartile range), respectively.	Dismantling, sorting, shredding, and open burning of electrical wires/cables and circuit boards, and Styrofoam.	---	Elevated PM and PAH levels for workers that burned and dismantled. Both exceeded standards or risk-based guidelines.	Kwarteng et al. (2022) Method: USEPA (2009).

It is worth noting that children are generally the subjects of the studies due to their multiple exposure paths and because they will face more serious health risks than adults, as explained in Section 4.2 (Li & Achal, 2020; WHO, 2021a). However, more attention is being focused on formal workers since “challenges still remain in assessing and controlling chemical exposures regularly found in this industry” (Ceballos & Dong, 2016, p. 164).

Even though this research is based on informal and semi-formal settings the latter can be compared to formal facilities. Hence, it might be relevant for this sector to understand the risks associated with e-waste management under regulated labor conditions. Regarding chemical exposures, in 2016, Ceballos & Dong (2016) conducted a literature review of 37 publications from four databases (PubMed, Web of Science, Environmental Index, and NIOSHTIC-2). To their knowledge, it was the first publication uniquely focused on the formal e-recycling industry. They suggested that:

- Based on documented cases of e-recycling workers, take-home exposures are likely.
- Formal e-recycling facilities in the US under regulatory compliance may not necessarily protect workers' health given the lack of systematic testing for some chemicals, the outdated lead occupational guidance values, and the limited number of limits for most organic chemicals of concern (e.g., FRs, PCBs).
- Reported worker exposures often exceed recommended occupational guidelines for metals and reference groups for brominated flame-retardants.
- There is a high potential for pollutants' transport into the environment from these facilities since air, dust, and soil concentrations of metals and organic chemicals were found inside or near the facilities and are generally higher than in reference locations.

Another evaluation of occupational exposure at a formal e-waste recycling company conducted by NIOSH (2019) determined that:

- Employees in charge of shredding should be subject to blood lead level testing.
- Dry sweeping should be prohibited in order to reduce the transport of contaminated dust and be replaced by wet cleaning methods or high-efficiency particulate air vacuuming.
- Employees should be provided with a lead-removing product to wash their hands before eating, drinking, smoking, or leaving work.
- The proper wear and use of N95 respirators is key in reducing exposure.

2.4.6 Conclusions of the Risk Assessment

The qualitative data collected from Site A as well as the quantitative data from the literature suggest likely chronic occupational exposures to dioxins, furans, HAPs, lead, and PM as a consequence of the open burning of copper cables that can produce or contribute to the development of cancer, neurodevelopmental, renal, cardiovascular (hypertension), and reproductive disorders.

With regards to Site B, our analysis suggests likely chronic occupational exposures to e-waste-related compounds for their activities of manual disassembly, shredding, sorting, and refurbishing. We conclude that there is unlikely chronic occupational exposure related to the open burning of copper cables because it is an activity that is rarely performed. However, as explained below, risk reduction measures related to the open burning of copper cables must be considered at this site, too.

Although the practices observed in both study sites are not as frequent as at the most studied e-waste sites in Ghana or China, enough evidence is available to take a precautionary approach towards occupational exposure and take-home exposure to protect informal and semi-formal e-waste workers in general, those workers that are more vulnerable (e.g., women, individuals with chronic diseases), their families, and neighbors.

First, even with identified gaps in existing literature, extensive evidence strongly suggests causal links between exposure to chemical compounds present in e-waste and adverse health outcomes, as presented in Section 4.3 and Section 4.5. In particular, old and modern cables are likely to contain lead and other hazardous substances that are released during open burning, and no levels of lead can be considered safe (Section 4.3). Second, as explained in Section 4.2, workers and their families are usually exposed to lead and other chemicals due to other e-waste management practices and sources, which suggests multiple exposure pathways. Third, the people under study live and work in vulnerable environments, are socially marginalized, and do not have access to proper health systems or occupational safety schemes, three aspects that increase their vulnerability. Fourth, according to our observations of the practices at both sites, there is a likely take-home exposure by workers to the people living with them. Fifth, as presented in Section 4.5, scholars recognize that there is still a gap in research and practice to protect formal e-waste workers. Thus, if they are not fully protected by the current occupational standards, we argue that neither are informal nor semi-formal workers.

The same conclusions above apply to both sites. However, some considerations might be highlighted regarding their differences. As described in Section 3.1, many open burning points have been identified at Site A and burning is frequently repeated by different people. In contrast, at Site B, open burning is conducted in one specific site twice per year at maximum by the same group. This observation suggests that people at Site A are more frequently exposed to the pollutants released during the open burning of copper cables. Workers at Site B manage general e-waste daily, exposing them to a greater variety of EEE and associated compounds. However, Site B is located in an industrial location, and the cooperative under study is transitioning into e-waste formal activities, a situation that may allow for implementation of better control measurements and practices compared to Site A, where exposures are higher because of the intersecting working and living spaces. The differences between Site A and Site B suggest that even if risk management prevention interventions related to the open burning of copper cables are needed in both sites, these interventions might not necessarily be the same.

2.5 Workers' Risk Perception

Understanding risk perceptions is key for health risk communication programs and risk management in general because perceptions influence people's decision-making processes (Börner et al., 2015; Fischhoff, 2009; Jensen et al., 2021). This section provides some site-specific observations related to risk perceptions to inform future risk reduction interventions at Site A and Site B. It is not intended to serve as an in-depth study of perceptions and risk communication strategies, which should be conducted with a robust design by an interdisciplinary group of experts, including risk and decision analysts, behavioral scientists, and communication practitioners (Fischhoff, 2009).

Risk perception can be understood as “the capacity of an individual to interpret a potentially harmful situation based on individual as well as collective beliefs” (Börner et al., 2015, p. 1618). It can also be defined as the interpretation of risks in relation to the “objective risk.” Reflecting from this last definition, the identification of “objective risk” becomes crucial to understand risk perceptions. Section 2.4 aimed to respond to that need. As it was presented, in the case of health risks, we are typically dealing with objective measures of exposure and statistical probability of health outcomes. However, following the risk perception definition as Jasanoff (1993) claimed, risk is a construct and “does not exist in an objective space as an unchangeable feature of the physical world” (p. 124). Hence, it is worth keeping in mind that the definition of “risk” is constrained by different stakeholders' judgment.

When analyzing risk perceptions in occupational and take-home exposure settings, one should consider many factors that include culture, gender, educational level, previous experiences, emotions and attitudes (e.g., self-confidence), level of control of the situation, the origin of the risk, who is affected by the risk (e.g., children, pregnant women), knowledge and uncertainty, how the information is presented, and the impact of social media and other communication channels (Antolini, 2012; Börner et al., 2015; Pan American Health Organization, 2023).

According to many scholars (Decharat & Kiddee, 2022; Ntapanta, 2021; PAHO, 2023; Singhal et al., 2021), workers that burn cables and informally manage e-waste have a very low risk perception about their activities. PAHO (2023) indicates that it is a job reached out of necessity, they cannot escape risks easily, and in many cases, they do not believe that chemical risk their health. Shkembi et al. (2021) also stress that "the economic benefit associated with recycling e-waste may outweigh the perceived health risks of workers" (p. 2). These observations are not limited to the informal sector. For example, Jensen et al. (2021) observed that formal e-waste workers (operators) "often believed they were safe due to an absence of what they considered to be alarming symptoms and lacked an understanding that the effects from chronic mercury exposure may not be noticed right away" (p. 9). Furthermore, their perception might also change according to the task being developed. Singhal et al. (2021) explain that some workers believe that dismantling and segregating EEE does not release chemicals, so they are safe activities that do not affect their health.

From our research, we are not in the position to validate these assumptions at the study sites nor characterize perception as low, medium, or high, but we can enumerate a series of factors that were repeated in the interviews and workshops and might be indicating a common trend in the views of local e-waste-related stakeholders. We characterized these factors according to the impact they have on risk perceptions. Under this framework, "to decrease" risk perceptions means that the factor makes people attribute less severity to the objective risk. "To increase" risk perceptions means that the factor makes people attribute the same or more severity to the objective risk.

2.5.1.1 Factors that Decrease Risk Perception

1. *Living in the Matanza Riachuelo basin area.* This area is one of the most popular hazardous sites in the country in terms of environmental pollution of industrial origin (ACUMAR, 2021). The inhabitants are aware of many of the threats that exist in the places they live and work because they see or smell them, are affected by them, or have been told about them. Some have lost trust in the institutions that should ensure protection and information and blame the external sources of pollution, such as industries, the traffic, or the lack of waste management services. In this context, in accounts of the workers and some governmental officials, we observed a belief that exposures to lead and other substances of interest are not associated with e-waste management but rather with their exposure to a contaminated environment. However, some other governmental interlocutors, who are aware of these beliefs, still confirm that the primary source of lead is risky e-waste management practices. These tensions in perceptions could suggest that i) the risk information communicated to workers and authorities needs to be clarified, ii) not enough risk information is communicated, iii) the lack of trust in the

communicators is significant enough for the message to be dismissed, or as one interlocutor from the government suggested iv) “the order of priorities regarding their daily life makes these real risks invisible, since they (the informal workers) do not identify another possible way to survive.”

2. *Milk as an antidote.* In the same way that Ntapanta (2021) portrays that workers at an informal e-waste site in Tanzania regularly drink milk when they are managing e-waste or in situations of accidental ingestion of toxic substances, we have observed that it is also a widespread practice of “body detoxification” at Site A and Site B. Dietary calcium and nutritional status of iron and zinc can affect the absorption of lead (US ATSDR, 2020), however, the sources of these elements are constrained by workers' access to that food, in most cases, because of its cost[28]. We suggest further exploring if milk consumption might end up being the only prevention measure implemented by the workers due to their belief that it acts as an “antidote.” We also remark on the importance of providing clear messages about recommended or not recommended milk consumption not only for children but also for workers[29].

3. *Chronic exposure levels.* During our visits, we were informed by toxicologists that they usually do not observe elevated Pb levels in e-waste workers. Some agreed that “workers contaminate the environment and children more than they contaminate themselves.” In light of our findings from the literature review, these messages should be carefully analyzed and discussed when developing risk communication strategies because, as we explained above, no levels of lead could be considered safe, and the current threshold levels for Pb and other chemicals (such as dioxins and furans) may not necessarily protect workers. Furthermore, it is worth recalling that some authors claim that more attention should be given to organic compounds, especially chlorinated compounds, that are more toxic that the inorganic ones (Cesaro et al., 2019).

2.5.1.2 Factors that Increase Risk Perception

1. *The protection of others as a motivation to understand risks and act.* Within the groups of workers, a sense of care for vulnerable groups, such as children and mothers, was not only pointed out by many ACUMAR officials but also exemplified in the site visits and workshops. For instance, during the workshop at Site A, some workers asked if giving their children milk

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[28] Alternative sources of calcium might be yogurt, cheese, tofu, leafy green vegetables, or sardines (not necessarily cheaper). Good sources of iron include liver, fortified cereal, cooked legumes, and spinach (US ATSDR, 2020).

[29] For example, in SRT (2018) it is stated that “now we know that milk increases the metal (lead) intake, thus, its use as an occupational preventive measure is not recommended” (p. 8, non-official translation).

was an appropriate risk reduction measure. Similarly, Jasanoff (1993) argues that parental care about children that could be affected by chemicals has the power to convert laypersons into "amateur toxicologists" (p. 130). We also evidenced that many families regularly take their children to the health units located at Site A for biomonitoring. This observation is particularly important for risk communication measures since the message to be sent can be developed according to these kinds of motivations.

2. *Previous experiences with chemicals and the learning process.* During the interactive workshop activities, most workers actively participated when asked to identify risks and chemicals. Lead, copper, and PVC were the main e-waste-related chemicals identified by workers during the activities. Other chemicals that are part of their daily routines, mostly bleach, turpentine, and agrochemicals, were also named. Many workers referred to examples of familiar situations about exposure to toxic chemicals and their effects and explained what they learned after those experiences. We see, then, that as Jasanoff (1993) claims, "given appropriate stimuli, the 'lay person' can become an 'expert' in a very short span of time, and [their] expertise can be all the more formidable because it combines formal technical knowledge with local knowledge that is as relevant as it is unstructured and informal" (p. 130).
3. *COVID-19 and best practices for preventing take-home exposure.* Because of the pandemic that began in 2019, some workers claimed that they started taking more preventive measures such as using masks, more frequent hand washing, and changing clothes before entering their houses. For future interventions, it might be worth making the most of the momentum and learnings associated with this specific situation in the global history and using it as an example of how "invisible matter" (viruses, chemicals) could be dangerous to human health.

2.6 Conclusions

In the present work, we recognized that although there have been efforts made by local authorities to prevent and reduce chemical risks associated with e-waste management, their actions are still not enough to "promote the visibility of the problem, to act on its transformation, disseminate what are the true conflicts, limitations, restrictions and situations" (Antolini, 2012, p. 125) in the study sites, and other sites with similar characteristics. Knowing the high probability of chemical risk associated with burning e-waste in both contexts, we reinforce the message of Heacock et al. (2018) on the need to implement concrete and effective risk prevention measures adjusted to the context that could, at the same time, promote the local economy and respect the knowledge gained by informal and semi-formal workers. We recommend that future risk assessments and definitions of risk management measures replicate collaborative, participatory, and mixed methods, recognizing that the stakeholders—workers, their families, and neighbors—are often individuals who have developed the "art of living" in polluted worlds (Ntapanta, 2021, p.10) and "are capable of learning extraordinary amounts of technical information, and indeed of participating actively in creating relevant new knowledge" (Jasanoff, 1993, p.130). According to our findings, the interventions at Site A and Site B should be focused on alternative, just, and economically feasible copper cable treatment options in the long term, and preventive measures in the short-term, such as the use of appropriate tools and personal protective equipment as well as training and other occupational safety measures.

CHAPTER 3

INTERVENTIONS TO PROMOTE SAFER WORKING CONDITIONS IN INFORMAL AND SEMI-FORMAL E-WASTE RECYCLING SETTINGS: THE CASE OF COPPER CABLE TREATMENT

3.1 Introduction

Although informal e-waste management is a topic that has been studied for years, the current scientific literature is mainly focused on exposure and effects assessment (Daum et al., 2017)–mainly for women and children–and does not precisely and contextually address interventions in the occupational sector (World Health Organization, 2021a). In a previous publication on interventions (Schlezak et al., 2022), we remarked that at a global e-waste workshop in 2017 it was agreed that "at the end of the day, the people involved in these activities need solutions. (…) We have to start assessing the effectiveness of the Interventions so that countries can implement them" (*E-Waste: Prevention Intervention Strategies Meeting Summary*, 2017, p. 20).

Along these lines, as some scholars argue, interventions should consider site-specific and simple solutions to minimize health and environmental risks (Comesaña García, 2019; Heacock et al., 2018; Lundgren et al., 2012; Prakash et al., 2010) "without sacrificing the economic and social benefits it now offers to local industry and community" (Chi et al., 2011, p.740). However, the technological interventions that have aimed to reduce risks in vulnerable contexts rarely supported the socioeconomic development of low-income recycling communities. Furthermore, the voices of these workers are often sidelined in the scientific literature, as illustrated by Daum et al. (2017) and the WHO (2021). In light of these claims, the Pan American Health Organization (2023) emphasizes that informal e-waste workers should not only be recipients of public policies but also partners in the search for solutions. Due to their acquired experience and knowledge while carrying out their tasks, they are necessary actors for the improvement of their living and labor conditions.

Some global experiences and guides on risk-reduction measures in the e-waste sector are available in the literature (Chou et al., 2021; Davey & Walsh, 2019; Schluep et al., 2015; Sepúlveda et al., 2010) and are worth exploring since, as stated by Heacock et al. (2018), "while solutions to reduce exposure and protect human health must be locally tailored, we can learn valuable lessons from work that has been done" (p. 221). In Schlezak et al. (2022), we briefly described and analyzed three e-waste intervention projects in the Global South: "Enhancing Informal Electronic Waste Recycling Tools and Methods" conducted in Thailand by the Exposure Research Lab at the University of Michigan (Chou et al., 2021; Coulentianos et al., 2021); the project "Transforming Agbogbloshie: From toxic dump into model recycling center" coordinated by Pure Earth in Ghana (Asante et al., 2016; Heacock et al., 2018; Muntaka Chasant, 2019; Pure Earth, 2015); and the Chinese prohibition of informal recycling and installation of an industrial park in Guiyu (Chi et al., 2011; Davor Mujezinovic, 2019; Feng, 2021; Heacock et al., 2018; Standaert, 2015). With different approaches, these interventions dealt with occupational risks. As a result of the analysis of their successes and failures, we observed the importance of including a thorough process of workers' participation from the early stages of design. A participatory problem definition and project design could avoid solutions not adequate to the context and with the potential to harm the ones that they aim to protect. In the paper, we also proposed a model to compare the purpose, methodology, and expected outcomes of these and future interventions, by applying the Engineering and Sustainable Community Development criteria (Bridger & Luloff, 1999; Lucena, 2014). The model was a preliminary approach that aimed to contribute to the global discussion about the transition into best practices in informal and semi-informal contexts by including other design factors to consider besides cost, timeline, and function. However, more specific insights are needed to promote successful site-specific interventions.

3.1.1 E-waste Interventions: State of the Art in Argentina

Since the 2000s, Argentinian regulators and scholars have progressively focused on e-waste management. As shown in Table 3.1, although this compilation of studies is not comprehensive, we observe that the focus has been mostly placed on the broad understanding of the activity in the country from different perspectives. Social, environmental, material, and health aspects were mainly addressed rather than specific interventions to reduce formal, semi-formal, or informal occupational exposures. However, since 2019, mostly motivated by the ILO, greater attention has been paid to the labor sector.

Table 3.1 Literature review of Argentinian e-waste-related publications. Not comprehensive.

Year	E-waste-related topic	Type of publication	Author(s)
2007	Market description	Independent report	Protomastro
2011	Comprehensive analysis	NGO publication	Greenpeace
2013	Comprehensive analysis	Book chapter	Protomastro
2014	Best management practices	MERCOSUR publication	Protomastro
2018	Conceptual analysis	Peer-reviewed publication	Clinckspoor

Table 3.1 Continued

Year	E-waste-related topic	Type of publication	Author(s)
2018	Comprehensive analysis	Book chapter	Clinckspoor & Suárez
2019	Environmental Health	Conference paper	Comesaña García
2019	Labor statistics	ILO publication	ILO
2019	Best management practices	Guidance document	Salcedo et al.
2019	Comprehensive analysis	Peer-reviewed publication	Rodríguez
2020	Stakeholders (Mar del Plata)	Peer-reviewed publication	Clinckspoor & Ferraro
2020	Lithium-Ion Batteries Recycling	Peer-reviewed publication	Dubois et al.
2020	Labor: sectorial description	ILO publication	Maffei & Burucua (ILO)
2020	Lithium-Ion Batteries Recycling	Peer-reviewed publication	Marcoccia et al.
2020	Comprehensive analysis	Government publication	MAyDS in Argentina
2020	Environmental Health	Conference paper	Zavatti et al.
2021	Occupational safety	Undergraduate Thesis	Berardi
2021	Legal analysis	Peer-reviewed publication	Clinckspoor et al.
2021	Comprehensive analysis	Government publication	Burastero
2022	Economic analysis (Bahía Blanca)	Master Thesis	Harguindeguy
2022	Comprehensive analysis (Bs. As.)	Undergraduate Thesis	Burastero

National labor statistics and descriptions of the different sectors are improving, and local regulations have been published (e.g., Resolution No. 269/19 in 2019, in Buenos Aires). However, there is still a gap in understanding e-waste-specific occupational risks and risk management measures to protect workers. This gap in occupational safety knowledge and practice is not only seen in the country. For example, as mentioned in Chapter 2, the US National Institute of Occupational Safety and Health identified that work is needed, particularly for occupational exposure to flame retardants in the e-waste sector (NIOSH, 2019).

In a context of global and national economic crisis, growing electrical and electronic equipment (EEE) demand, and growing generation of e-waste, it is imperative to prioritize the population that is contributing the most to the e-waste circularity: e-waste formal, semi-formal, and informal workers, including urban recoverers and cooperativists. Furthermore, promoting safer occupational environments will contribute to safer communities in general.

3.2 Objectives

Having identified the risks in Chapter 2, through participatory qualitative methods and research, in Section 4 we propose alternatives for interventions to minimize risks in e-waste settings, based on the NIOSH Hierarchy of Controls within the framework of occupational safety (US NIOSH, 2023). Acknowledging that the Hierarchy of Controls has been developed to be implemented in formal contexts, we apply Pinch & Bijker's (1984) *interpretative flexibility* concept used for artifacts to open this method to more than one interpretation. Hence, our proposed interventions are adapted to the local context of Site A and Site B in Buenos Aires, Argentina.

Under this framework, we also acknowledge the multiple problem definitions that might arise because, as Pinch & Bijker (1984) claimed, "a problem is only defined as such, when there is a social group for which it constitutes a 'problem'" (p. 414). Although the "problem" has been set from the environmental health perspective, the qualitative approach helps us understand and analyze the many definitions of the "problem," depending on the different stakeholders we interacted with, including urban recoverers, cooperativists, government representatives, and scholars. Hence, throughout this chapter, we analyze how current and potential copper cable treatment processes have different implications for them. In Section 5, the advantages and disadvantages of the different proposed interventions are analyzed based on four Engineering and Sustainable Community Development (ESCD) criteria (Bridger & Luloff, 1999; Lucena, 2014; Schlezak et al., 2022). We conclude by providing insights to inform projects and policies to minimize harm within low-income e-waste communities and promote local socioeconomic development with long-term and sustainable results.

3.3 Methods

For the development of this research, qualitative methods have been used, including participatory observation, semi-structured interviews, focus groups, and workshops that were complemented by a literature review. An in-depth description of the qualitative methods was included in the Introduction and Chapter 2.

3.3.1 NIOSH Hierarchy of Controls

The NIOSH Hierarchy of Controls was the selected framework to propose and analyze the interventions presented in this work (US NIOSH, 2023). It is a methodology used to determine which actions will best control exposures and reduce occupational risks at working facilities. It has five levels of action to reduce or remove hazards: elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). The preferred order of action based on descending effectiveness is generally illustrated as an upside-down pyramid from elimination to PPE.

1. *Elimination* focuses on removing the hazard at the source. For example, it could be achieved by changing a process, selecting new equipment, or following a different procedure. When the hazard is eliminated, no exposure to this hazard occurs. Hence, this is the most effective measure for risk control.

2. *Substitution* is using an alternative that replaces the source of the hazard, which should be safer, reduce the potential for harmful effects, and represent lower and less potential new risks.

3. *Engineering Controls* are the arrangements that can reduce or prevent contact of the hazard with workers, for example, by modifying equipment or the workspace, using protective barriers, or ventilation. According to NIOSH (2023), the most effective controls have the capacity to remove or block the hazard at the source, need minimal user input, prevent their modifications or interference, and do not hinder nor interfere with the process.

4. *Administrative Controls* are work practices, such as training, job rotation, and limiting access that reduce the duration, frequency, or intensity of exposure to hazards.

5. *PPE* is the last and least effective level. It consists of equipment that workers wear to minimize their exposure—for example, gloves, safety glasses, hearing protection, hard hats, and respirators. Together with administrative controls, PPE requires significant effort by workers and employers. The use of PPE requires the implementation of a program that defines which equipment should be used and how, inspection and replacement procedures, employee training, and monitoring for continued effectiveness.

3.4 Applying the Hierarchy of Controls in the context of the open burning of copper cables at the study sites

In Chapter 2, we determined that potential chronic exposure to e-waste-related toxic substances is likely at study site A due to the open burning of copper cables. In this context, the hazard was associated with the substances released during the process, including those already in the cables and those generated as combustion products. Below, we present a contextual analysis of options for each hierarchy's level applied at Site A based on the previous risk characterization. Our analysis includes qualitative data from Site A and Site B that we gathered during interviews, site visits, participatory observations, and workshops.

An important consideration is that implementing the Hierarchy of Controls in the context of informal e-waste management requires a thorough analysis of roles. In the context of Site A, a mixed situation is presented, where many workers of a solid waste cooperative recycle e-waste individually, while in other cases people recycle individually, without necessarily belonging to that cooperative. Therefore, when applying the Hierarchy of Controls framework in this context, we must consider who the employer is. Is it the cooperative coordinators, even if they do not have a direct relationship with the activity of their workers related to e-waste? Are the workers considered self-employed? Is it the government? If so, which governmental entity? Since each proposed alternative has different ramifications , these questions are addressed differently for each case.

Our study is preliminary, so an exhaustive analysis of these different interventions is not offered. However, some contributions from literature, local key workers, and informants are described below. We hope that they serve for future and more detailed analysis.

It should be noted that, in both Site A and Site B, we observed a high interest in our proposals because the focus was not only on reducing risks but on their economic benefits. As previously stated, we acknowledge that the stakeholders define the problem differently. For some, the introduction of a new process implies higher incomes because of the increase in the quality and price of the final product (Davis & Garb, 2015). Hence, our approach was not constrained to the environmental health perspective but also focused on the workers' economic interests.

3.4.1 Elimination

3.4.1.1 Elimination of Any Treatment Activity of Copper Cables

This proposed alternative aims to eliminate the hazards' primary source, i.e., the chemicals released as a product of the current cable treatment methods. Following this approach, urban recyclers should limit their activity to collecting, classifying, and transporting cables to users or treatment industries, or reconvert their activity from recycling to repair and refurbishing, using the recovered cables to the greatest extent possible. Such an intervention not only depends on the willingness of the workers—which is equally necessary for any of the CSO proposals—but also on external factors since it is one of the most radical proposals in terms of affecting the current recycling activity.

The prices for non-treated cables are usually much lower than stripped cables and somewhat lower than burned cables. Therefore, one option for the collection business to be just as economically beneficial as burning would be to equalize the purchase price. This option inevitably depends on a market intervention, which in the local context has a strong informal nature—as observed in the collaborative map in Figure 2.5, there are at least 14 small purchase points of metals in an area of fewer than two ha.

Market interventions can occur through incentives to small merchants to prioritize the sale of non-treated or stripped cables over burned cables or through regulations that set limitations on the burned cables market. Another option is to centralize the collection of non-treated cables and sell a large number of classified cables to the industry, skipping the intermediaries. This alternative should be evaluated in light of the potential impacts on the local economy.

Insights from the literature

To a different extent, this intervention might replicate the concept of the "Best-of-2-Worlds" philosophy (F. Wang et al., 2012) that seeks to "institute a commodity chain between high-income and low-income countries to take advantage of low-cost labour in the latter for manual disassembly into high-quality material fractions that are then exported to high-technology refineries in the former" (Lepawsky et al., 2017, p. 87). Even if this approach suggests positive environmental impacts, there are some critiques about it from the socioeconomic side since it would restrict the possibilities of smaller e-waste businesses to grow and extend their markets and skills (e.g., repair, reuse, repurposing) (Lepawsky et al., 2017). Under the current scenario of e-waste labor-related activities at Site A, eliminating the collection and/or treatment of copper cables would not be aligned with the theory and practice of Engineering and Sustainable Community Development since it would imply taking from the inhabitants a relevant source of income without offering any alternative for their socioeconomic development (Bridger & Luloff, 1999; Lucena, 2014). Furthermore, Chi et al. (2011) suggest that the flexibility of informal recycling makes it relocatable and hard to control and express that "radical government interventions, aiming at forbidding informal recycling by enforced removal of operation, often find it difficult to achieve their planned objectives" (Chi et al., 2011, p. 738).

Insights from workers

Our study indicates that workers might not support the alternative of converting the collection and treatment activity to collection and classification only. This restriction could be interpreted as mobilizing management power to industries with the necessary cable recycling technologies. However, this is a very preliminary observation.

Another relevant point is the willingness of the workers to convert their work from recycling to repair and refurbishment. This proposal was not a very discussed alternative with workers at Site A. However, from our interviews and visits to other sites, we can suggest that repairing could become an activity of interest to them as long as it is accompanied by access to education and technology. For example, at Site B, four of the five workers expressed an interest in learning how to repair electronic equipment and refunctioning general equipment. Promoting these activities contributes to their training and skills—as further developed in Chapter 4—. Furthermore, in the literature, these activities are preferred over recycling under the framework of the waste management hierarchy (UNEP, 2015).

Regarding the alternative of intervening in the market, it must be considered that the small informal buyers of metals in Site A do not accept cables with plastics, according to the workers. If they did so, they likely would continue with the open burning. Therefore, this option must also be accompanied by an intervention focused on the intermediaries. Otherwise, the problem would not be adequately addressed and would displace the same concerns towards them.

Insights from other local key informants

One informant claimed that industries only accept non-burned cables and pay more for already classified cables. However, to get materials to industry, a large number of cables is needed. In this sense, workers shared that a recyclers' federation usually acts as an intermediary for some solid waste, supporting cooperatives by collecting the small amounts of material they generate. In this way, worker federations could take a significant role in buying and selling non-burned cables. However, since e-waste is an incipient waste stream within the social economy in Argentina, they are not currently buying cables or copper.

For any of the proposed alternatives, it is necessary to recognize that opening up to different markets requires specific knowledge of actors and trade chains. Due to the complexity of e-waste, getting this market data becomes complicated and time-consuming. Some informants also stated that, by themselves, activities such as repairing and refurbishing are not economically sustainable. Therefore, it is suggested that any proposal for reconversion or intervention in the market be given with economic support for the workers.

3.4.2 Substitution

3.4.2.1 Wire Stripping as a Substitute Process to Recover Copper

The proposal most analyzed and discussed with the workers in our research has been the substitution of open burning, which is currently the primary process implemented in informal settings for separating copper from the other materials that make up the cables (mainly PVC, according to Cesaro et al., 2019).

Li et al. (2017) claimed that the main cable treatment techniques include mechanical treatment, freezing, ultrasonic separation, high-pressure water jet, heat-recovery, and chemical treatment in most formal enterprises. In this level of the Hierarchy of Controls, we propose two alternatives adjusted to the context of Site A. On the one hand, a low-cost mechanical manual stripping tool is designed specifically for medium and small diameters (less than 1cm) cables. On the other hand, an electromechanical process is proposed that works for most cables.

Considering that cables are produced in vast variety, the literature indicates that pre-sorting of cables should be conducted before both processes to make recycling the metal and plastic fractions easier. The segregation should be based on metal type, insulation material, conductor diameter, and length (Stockholm Convention, 2004). Li et al. (2017) suggest that the waste cable is divided into three types: 1) Cables with large diameters, stable composition, and uniform specifications; 2) Cables with different compositions of insulating layers, intermediate diameters, and mixed types; 3) Cables with small diameters and mixed types.

3.4.2.2 Wire Stripping as a Substitute Process to Recover Copper: Manual Stripper

Manual cable stripping is the cheapest method for copper cable recovery, but the production rate might be lower. However, the copper is completely recovered since the metal can be separated from the plastic insulation (Stockholm Convention, 2004).

Our proposed tool consists of two pieces of wood, a blade, two screws, two nuts, and two washers (Figure 3.1). It was built using a grinder and drill in less than 30 minutes. The cost of the materials is approximately 800 Argentine pesos (with the informal exchange rate, which translates into approximately 2 US dollars). The wood was obtained from a local furniture shop that discarded small pieces.

Figure 3.1 Prototype of a low-cost wire stripper (Author. Adapted from Backyard Art, 2020)

The prototype was inspired by an online video about a homemade wire stripper (Backyard Art, 2020). The mode of action is introducing the cable and pulling so that the blade's edge breaks the plastic cover. It was designed to be transportable but could also be attached to a fixed surface, such as a table. Our prototype has one main modification, three holes of different diameters (2 mm, 3 mm, and 5 mm). Similar designs can be found on platforms such as YouTube by searching words like "cable stripper" or "wire stripper." There are also a large number of inexpensive electromechanical wire stripping tools available.

In Table 3.2, we provide a comparison between the open burning and the manual stripping in the context of Site A.

Table 3.2 Comparison between the open burning and low-cost stripping process.

Factor	**Open burning of copper cables**	**Manual wire stripping**
Time	20-30min per skein of cables (according to workers and informants) Preparation + burning + cooling	30 sec per meter of cable (rough estimation) Untangling + Stripping
Frequency	Once they reach a certain number of cables.	It could be performed even with one cable.
Materials needed	Fuel (ethanol), board, paper, or wood, and a lighter (every time).	For construction (once): Blades, wood, screws, drill, grinder. Blades (when dull).
Pros	Existing local knowledge. Cheap and accessible materials. Fast operation.	Higher quality of the copper and higher price. Cheap and accessible materials. Easy to carry. Work can be performed anywhere. Low chemical risks.
Cons	High chemical risks. Health and environmental effects. Claims by neighbors. Need to move far from households. No value obtained from plastics. Lower price.	Need for untangling, need for adjusting to different cable sizes. Ergonomic and physical risks (cuts). Generation of plastic waste (also subproduct).

Insights from workers

In none of the study sites and interviews did any participant report knowing this stripper design. Some positive comments about the tool were:

Workshop at Site A – "Está re bueno." "Cheto, mirá." "Re cheto." "No lo tires en el medio porque te lo van a sacar."

ENG: "It's really good," "Look at that, it's cool." "So cool." "Don't throw it in the middle because they're going to grab it."

Workshop at Site B - "En 5 minutos te lo armamos." "Está para llevar a casa."

ENG: “In five minutes can we put it together.” “I could take it home.”

The previous expressions showed us that the tool was well-received by most of the workers in the workshop. However, some critical considerations about the design and productivity of the tool also emerged from our interactions:

Time: “Tardás mucho.” “Te volvés loco”

ENG: “It takes a long time.” “You can go crazy.”

Needed materials and tools:”¿Y, pero si no tenés moladora?” “Hoy en día nadie te quiere prestar la moladora.” “¿Y si no tenés los materiales exactos?”

ENG: “What if you don't have a grinder?” “Nowadays nobody wants to lend you the grinder.” “What if you don't have the exact materials?”

Sub-products: “¿Me queda el plástico, no?”

ENG: “Then I have the plastic, right?”

It is essential to recognize that time is valuable for Site A workers because, among other reasons, they hold other jobs. They also dedicate much of their time to caring for their children and cohabitants.

While showing interest in a non-machine proposal, a cooperative worker at Site B also pointed out some of its complexities. This worker emphasized that the several types of cables with multiple layers, mixed materials, and different hardness could make the process difficult.

Insights from other key informants

One of the government officials that attended the Site A workshop brought an extra benefit associated with wire stripping. The participant called attention to the fewer exposure precautions workers would take if they changed their processes. For example, if there is no other exposure, they could avoid taking their clothes off, washing them separately, or having to go to the riverbank.

Regarding the difficulties, as previously described based on the literature, an expert with extensive experience in the e-waste field highlighted that small-diameter cables are complex to strip and that it is recommended to shred them and then separate the materials using a densiometric table that divides them. This approach will be explained in the next section.

3.4.2.3 Wire Stripping as a Substitute Process to Recover Copper: Electromechanical Process

An alternative to individual and manual stripping is to locate cable treatment machinery at the local cooperative at Site A so that urban recoverers (associated or not associated with the cooperative) can treat the cables they collect there. This proposal has two main challenges. On the one hand, the level of acceptance of the cooperative to possess the machine and take a coordinating role, taking into account that it would imply sharing their space, their tools, and the costs. On the other hand, the willingness of the urban recoverers to transition from carrying out an individual activity into a collective activity would imply adjusting their dynamics. Likewise, in both cases, the cables needed to justify the investment and use of machinery should be analyzed.

There are two alternatives under this proposal. One option is the purchase and installation of a wire stripping machine, and another is the purchase and installation of several cable shredding and separation machines. The principles of both alternatives are described below, and the final products for both processes are granulated copper and PVC – if appropriate classification is implemented.

Wire stripper machines – Stripper machines are appropriate for treating large-diameter, uniform waste cables (L. Li et al., 2017). These machines can process only single cable strands at rates up to 60m/min or 1,100kg/min with cable diameters ranging from 1.6mm to 150mm (Stockholm Convention, 2004). As shown in Figure 3.2, a stepping motor and wheel-clamped drive the cable and wire movement through the cutter.

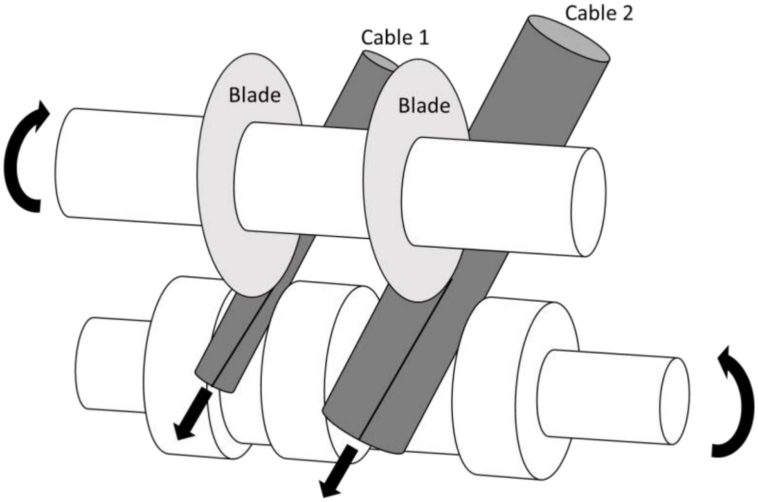

Figure 3.2 Schematic representation of electromechanical stripping (Author).

Chopping or crushing- This is a process that can treat cables of different types and dimensions and, according to Li et al. (2017) and the Stockholm Convention BAT-BEP group (2004) involves the following steps: 1) *Pre-sorting* according to cable type. 2) Pre-*treatment & chopping* where long cables are reduced to one meter and densely baled cables are broken into loose streams. Superfine wires and grease or tar-filled cables should be removed. This process could be optional in smaller facilities. 3) *Granulation* separates metals from plastic insulation and jacketing. Small amounts of metals might remain locked in the plastic and be lost as waste. 4) *Screening and reprocessing* of oversize material in the granulator. Dust collection and filtering should be conducted. 5) *Separation* through density techniques (fluidized bed separators) or dry electrostatic separators based on the conductivity differences of the copper and the plastic sheath. Note that Li et al. (2017) also include a magnetic sorting process before step 5.

Insights from the literature

There are experiences of local development of this technology in Argentina. For example, Clinckspoor & Zulaica (2022) detected that the workers of a private e-waste treatment company in Mar del Plata (Buenos Aires), in a simple way and without a huge investment, were able to produce a densiometric table where the metal is separated from the plastic by magnetization, as shown in Figure 3.3.

Figure 3.3 Example of a densiometric table built by an e-waste worker in Buenos Aires. (G. L. Clinckspoor & Zulaica, 2022)

Diverse options can be explored to afford the purchase of such machinery. One option could be national government programs that provide tools and machines to waste cooperatives (Ministry of Social

Development in Argentina, 2022). Another option is through the support of waste picker federations, which, according to our interactions with key informants, often provide support to their members. Also, given the shared interest between environmental and health authorities at different levels of government, it would be possible to explore the possibility that the purchase of such machinery is framed within their socio-environmental and development projects. Some options for access to international financing could also be explored, for example, through the multiple projects that are created and offered on different platforms of the United Nations, ILO, WHO, and ITU, as well as national or international non-governmental organizations (see Table A.1 in Appendix A).

Insights from workers and key informants

Most of the opinions for this proposal come from the workers and informants related to Site B since the amounts of cables they manage could justify the use of machinery. One of the most frequent questions from workers is to whom they would sell the large amounts of high-quality recycled copper and plastic they would obtain. In this regard, a key informant stated that at least three companies located no more than 30 minutes from the study area would receive the materials.

When designing or selecting a machine, an informant highlighted that there must be a profound understanding of the context, the daily dynamics, and its use. The machine should not be strictly attached to the technology itself. Therefore, as we previously anticipated, it is essential to reflect on how the proposal would change the way of working for recoverers and cooperative members. In this regard, it is also important that, as some interviewees highlighted, the workers of Site A are used to moving short distances or not moving at all, so the location of the machinery should also be evaluated. In this case, the cooperative is close to most urban recoverers' households.

Another important consideration is that automated machinery has the potential to replace jobs. In this regard, an informant made a reflection on the management of solid waste that deserves to be analyzed:

"(Las extrusoras) son re piola, pero les dan trabajo a solo dos personas. Entonces, el agregado de valor laboral se le da a la parte previa. A veces la máquina no te da el objetivo de oferta de trabajo que querés, entonces el foco lo ponés en otra parte."

ENG: "(The extruders) are very good, but they only give work to two people. So, the labor value added is given to the previous part. Sometimes the machine does not give you the job offer objective that you want, so you have to put the focus elsewhere."

It should be noted that, unlike the traditional economy, keeping jobs is usually a priority over productivity for the social economy. In this sense, the previous informant considered that the classification of the waste stream is a crucial step that not only contributes to process efficiency and profitability but also to job creation. However, there is an information gap at the cooperative level on the different types of cables and their composition, which hinders the classification process. Criticizing the lack of regulation of e-waste at the national level in comparison with other regions, our interlocutor said:

“No es lo mismo cuando hablamos de países como el nuestro, en donde no tenemos regulado nada de todo esto y te vienen cables de 50 tipos distintos. Mirá, este es mi cable de cargador que parece un elástico. No entiendo qué tiene por afuera.”

ENG: “It's not the same when we talk about countries like ours, where we don't have any of this regulated, and then 50 different types of cables come to you. Look, this is my charger cable that looks like a rubber band. I don't understand what the cover contains.”

Another complexity of working with large amounts of cables has to do with the storage space since it is often not enough for the stock handled by small cooperatives.

3.4.3 Engineering Controls

3.4.3.1 Controlled Incineration

In this case, the proposal consists of the complete combustion of plastics in controlled atmosphere incinerators. This engineering control proposal was one of the least discussed during our interactions, as it has relevant limitations. First, heat technologies for processing e-waste exist in the formal recycling sector but are not preferred over chopping or stripping because incineration is not consistent with the concept of circular economy and the hierarchy of waste management options (L. Li et al., 2017; Stockholm Convention, 2004; UNEP, 2015). Furthermore, as stated above, the quality and value of incinerated metal are lower due to oxidation. Second, an effective flue gas cleaning system is required since the combustion releases contaminants, such as dioxins, carbon dioxide, sulfur dioxide, hydrogen chloride and fluoride, and dust (see Chapter 2). For instance, fabric filters could be employed to collect particulate matter contaminated with dioxins, and wet alkaline scrubbing could be used for SO_2 and hydrogen chloride and fluoride removal (ibid). Hence, this process requires a continuous supply of off-gas cleaning material as well as the management of the waste generated, which is considered hazardous. Furthermore, it should also be subject to continuous monitoring of temperature and emissions. Third, the recycling efficiency decreases, since for every ton of cables, 20 to 30 kg of copper is lost during burning (Chen 2012 in Li et al., 2017).

Implementation of this technology could be framed in the same way as the machines described in the previous section, e.g., a furnace installed at one point (for example, the cooperative) could be used collectively. However, it should be noted that this kind of technology is costly and generally designed for industrial facilities.

3.4.4 Administrative Controls and PPE: Designated use of Land, Provision and Use of PPE, and Education

Regarding the informal sector, as indicated in Chapter 2, health management measures are mainly focused on the protection of women and children from indirect exposure (take-home exposure, contact with contaminated soil and food, air, and water contamination), while recommendations focused on occupational exposure are not as frequent. Here we have focused attention on the measures that may be relevant for informal workers at Site A, while some may also be useful for workers at Site B, though the latter must comply with current local regulations (Resolution OPDS No. 269/19, 2019).

Insights from workers

As explained in Chapter 2, although some factors suggest a low perception of risk within the e-waste workers' communities, most workers responded positively to the transfer of knowledge of occupational health and safety issues. As explained by some informants related to cooperatives, there is an increasing interest on the part of cooperatives in training, either in operational matters or in those related to job security.

“Me gustaría aprender más sobre seguridad e higiene porque nunca le di bola, siempre fue desarmar y romper, y que sea lo que sea… Sin embargo, es bueno aprender eso de seguridad e higiene y cómo tratar los materiales.”

ENG: “I would like to learn more about safety and hygiene because I never cared about it, it was always about disassembling and breaking, and whatever… However, it is good to learn about safety and hygiene and how to treat the materials.”

The interest is also justified by the requirements of the regulatory framework of the activity since Article 6.b. of Resolución OPDS No. 269/19 (2019) establishes that e-waste cooperatives in Buenos Aires must accredit training.

Listed below are some barriers from the workers' perspective regarding knowledge transference related to occupational safety and hygiene measures.

(Site A)**:** “Muchas veces cuando las necesidades básicas no están satisfechas es muy difícil que la EPP funcione si lo básico no está completo.”

ENG: “Many times, when basic needs are not met, it is complicated for PPE to work if the basics are not complete.”

(Site B): “Una chica se quemó y un compañero le dijo “tirale lavandina”, y yo me puse a discutir. “Si vos le tirás lavandina a la piel y no tiene la primera capa se va a lastimar el tejido.” Y me decía, “¿vos qué vas a hacer?” “Yo no sé nada” le digo, “si vas a hacer algo, haceme caso, agarrá jabón blanco y agua, y tiene que ser agua limpia. La de acá no te sirve. Usá agua mineral porque si no, se te va a infectar.”

ENG: “A girl got burned and a co-worker said, “throw bleach at her,” and I started to argue. “If you throw bleach on the skin and it doesn't have the first layer, it will hurt her skin.” And he asked me, “What are you going to do? I replied, “I know nothing. If you're going to do something, listen to me, take white soap and water, and it must be clean water. The one here is useless. Use mineral water because otherwise she will get infected.”

(Site B) “Nos pasó con un bidón no etiquetado, (el líquido) saltó y una chica quedó ciega. Lo primero que hicimos es llamar al (nombre del centro de ojos), ¿pero ahí qué hacés? ¿Agua? El agua de acá no es segura, está contaminada.”

ENG: “It also happened with an unlabeled container, (the content) splattered and a girl went blind. The first thing we did was calling the (eye center's name), but what do you do there? Water? The water here is not safe, it is contaminated.”

The stories above show that not only is it enough to provide hygiene and safety instructions in these contexts, but it is also necessary to carefully analyze the possibilities for workers to apply them. As indicated by some informants, the restrictions for water use also apply to the case of hand washing. In this regard, recalling the observations of NIOSH et al. (2019) about hand washing with a specific lead-removing product, it is crucial to analyze how accessible the product is in Buenos Aires and what is the purchasing and use capacity of informal and semi-informal workers.

Insights from other key informants and observations

PPE – Regarding Site B, an informant indicated that the access and use of the PPE are, to a great extent, the result of the comparativists' own demand since, at the time of the development of research, cooperatives were not covered by *the Law N° 24.557 on Occupational Risks* (1995). This situation changed with a new national regulation issued in September 2022 (Decree No. 651/2022, 2022). Under this new framework, cooperatives can be part of said regime at their own will.

In our visits, we noticed that PPE could be provided for cooperatives by municipalities, the provincial government, the national government, other cooperatives, or recycler federations. However, for the workers at Site A, the situation differs because not all of them belong to a cooperative, and those who are associates do not carry out their copper recovery activities as part of the cooperative. Therefore, it is necessary to establish how they can provide themselves with the necessary PPE for their work (gloves, mask, work clothes) since not all workers may have the resources to buy PPE, which is estimated to cost more than they can get for a kilogram of copper.[30]. This is a great example of why PPE, which is not a sustainable solution, should not be implemented as the only intervention for these workers.

These same considerations are important when indicating preventive measures requiring specific food purchases. For example, when advising sources of iron and calcium, it is important to consider the power of access to food and dietary supplements and adjust it to the possibilities of the population.

Prevention instructions- The indications should be contextualized. An example is the message a doctor from Site A left in the workshop.

“Prevenir, con lavado de manos, con cambio de ropa, no comer, no tomar, no fumar mientras queman porque las manos se contaminan, aunque lo hagan con un palo. Otra cosa es que, cuando uno quema, el lugar donde se quema queda contaminado, entonces no realizarlo donde juegan los chicos o en la casa. Por ejemplo, en la rivera.”

ENG: “Prevent, with hand washing, with a change of clothes, not eating, not drinking, not smoking while burning because the hands become contaminated, even if you use a stick. Another thing is that the place where you burn gets contaminated, so don't do it where the kids play or in the house. For example, do it on the riverbank.”

This message understands frequent practices (such as eating, drinking, and smoking) while burning. It is sensitive to misconceptions, such as believing that the exposure will be negligible by helping yourself with a stick. This message also gives options since it indicates not to burn near homes and places close to children but in remote places such as the riverbank. This indication would not be appropriate in a context where the aquatic resource is used for residential, work, or recreational activities. However, considering the local context where the aquatic resource is not suitable or used for any of these uses, it could be one of the most successful short-term options. However, as a result of this investigation, it would be desirable that the message improves to overcome the status quo.

An informant also highlighted the importance of messages not only being about scolding workers but offering them better alternatives with a positive impact on their tasks and relationships. For example, in the case of Site B, where a small food space next to the hazardous waste disposal site was identified as risky

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[30] The cost of gloves for chemical protection is approximately 900 Argentine pesos, and a protective mask for particulate matter is approximately 350 Argentine pesos. Source: mercadolibre.com.ar. Last access on March 13, 2023.

(Chapter 2), an informant remarked that the workers feel comfortable in that small space because they do not know people from other sectors of the cooperative. Our interlocutor then proposed the creation of a dining room, which would be a risk management measure and a meeting space[31]. This person also indicated that it is important that the message provided by the authorities to the workers is not biased towards holding them responsible for their own exposure and the indirect exposure of their family. The context in which they grew up and lived must be considered.

"Parece que por tu culpa tenés plomo en sangre. (…)Muchas veces no es así, mucho tiene que ver el lugar en donde ellos viven. No solamente es el trabajo, sino también de dónde toman agua, por ejemplo."

ENG: "It seems that because of you, you have lead in your blood. (…) Many times, it is not like that, a lot has to do with the place where they live. It is not only work, but also where they get water from, for example."

Furthermore, given that those who are dedicated to recycling e-waste also have a history of working with household waste, where the hazards and risks are different, a person familiar with the work in the Site B cooperative highlighted the importance of the message to workers being clear.

"Laburar con esto no es lo mismo que laburar con RSU"

ENG: "Working with this (e-waste) is not the same as working with RSU (solid waste)."

However, the interlocutor also pointed out that the message, which must be clear and contextualized at the level of training and education, should not have the objective of scaring workers but should seek to give them "appropriate knowledge." Instead of making workers afraid to work, the messages should look for a change in behavior. Highlighting the importance of incorporating a participatory and non-hierarchical dynamic in risk training, the informant commented about the workshop at Site B:

"Hay un poco de esa magia de bajar vocabulario técnico a territorio que amo(…). No fue desde un lugar de 'yo alumno, vos (profesor)'. Fue 'bueno, intercambiemos, pensemos, hagamos actividades en conjunto'."

ENG: "There is a bit of that magic I love of lowering technical vocabulary to the territory (…). It was not from a place of 'I am the student, you are the (teacher).' It was 'well, let us share, think, and do activities together'."

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[31] In the formal sector, most countries require break spaces like this, along with sanitation facilities.

Another point to highlight is the gender perspective in the design and communication of prevention messages. According to some informants, this vision is not new for ACUMAR officers since they usually implement it in their risk communication programs. This point is particularly important for Site A, where, in general, women are very receptive to valuable information for their children's care. They also have a fundamental role in take-home exposure since, as explained in Chapter 2, they generally perform the largest number of household tasks, including laundry.

Biomonitoring – A key instance of risk communication and preventive measures occurs before, during, and after biomonitoring campaigns. Before the extraction, it is important to recognize that this procedure can produce fear for the workers and citizens in general, as explained by an interlocutor. It was suggested that prior training instances be provided to counteract this fear. The training could include the activities, exposure, effects, the reasons for monitoring, how the procedure is carried out, and how the management of biomonitoring data will be managed. The same contents can be repeated during the extraction, providing additional consultation spaces. Then, responsibly, the institutions in charge of biomonitoring must ensure appropriate feedback of the results to the workers, with case a follow-up.

Peer-to-peer approach – The workers of the Site B cooperative frequently receive training from another cooperative with more experience. This demonstrates the potential for transferring knowledge and experiences from external sources and the core of workers. This transfer could provide added value since no one knows the work dynamics and complexities better than the workers themselves. This observation applies above all to cooperative workers since, in general, their conditions are better, taking into account the support networks that allow them to contact institutions and train each other (further information in Chapter 4).

As for the workers of Site A, although they work individually for their activities related to e-waste, other types of networks are equally important. For example, the participation of local organizations and institutions could play a key role in sharing occupational risk prevention messages. Our observations show a strong presence of schools, "comedores comunitarios" (communal food assistance providers), sports clubs, development associations, cultural centers, neighborhood front offices, and cooperatives in other areas. In this sense, an informant with more than a decade of experience working with the local population indicated the importance of "neighborhood leaders" to promote actions and behavior changes. Additionally, as we observed, the door-to-door activities conducted by ACUMAR are effective in engaging workers and their families in periodic health checkups, practice that could be also applied to awareness-raising and training activities.

3.5 Analysis of the Hierarchy of Control Proposals Based on the Adapted ESCD Framework

Using the model we presented in Schlezak et al. (2022) and the above-described observations, we grouped the factors affecting each intervention into the four adapted ESCD criteria (namely, political autonomy and self-determination; focus on local socioeconomic development; efficient and careful use of energy, natural resources and materials and social justice). In Table 3.3 the factors are listed and defined. Then, in Table 3.4 we summarized the main features of all the Hierarchy of Controls proposals adapted to the context of Site A.

Table 3.3 Description of factors used to analyze each proposed intervention under the adapted ESCD criteria.

Adapted ESCD criterion (Schlezak et. al, 2022)	**Factor**	**Definition**
Political autonomy and self-determination	Stakeholders involved (besides workers)	Key stakeholders for the design, implementation, and sustainability of interventions
	Reliance on external sources	Level of dependance on external funding, knowledge, power, and other resources
	Need for legislation	Level of dependance on a legal framework for the intervention to be successful
Focus on local socioeconomic development	Workers' willingness	Level of workers' willingness to change their activities and/or acquire new skills
	Operation and maintenance needs	Level of resources needed to operate and sustain the intervention
	Training and capacity-building needs	Level of new information and skills needed to design, operate, and sustain the intervention
	Quality of copper	Level of copper's quality obtained in comparison with copper from burned cables
	Quantity of copper	Qualitative comparison with copper from burned cables
	Affordability	Affordability considerations from the workers' perspective
	Economic compensation	Impact on workers' income in comparison with the open burning of cables
	Time needed	Time of proposed operations in comparison with the open burning of cables
Efficient and careful use of energy, natural resources, and materials	Use of energy and materials	Qualitative description of energy consumption and key materials
	Environmental burdens	Environmental risks and waste generation
Social Justice	Allocation of rights, resources	Brief analysis on potential allocation of power and resources among different stakeholders
	Impacts on human health	Human health risks

Table 3.4 Comprehensive analysis of the OSC proposals in the context of Site A.

ESCD criterion	**Option** **Factor**	**Elimination**	**Substitution**		**Engineering Controls**	**Administrative Controls and PPE**
			Manual	**Electromechanical**		
Political autonomy and self-determination	**Stakeholders involved (besides workers)**	Government. Small informal purchasers. Industries that treat cables.	Construction and maintenance: Cooperative. Local university or community college. Funding: Government. NGOs.		Construction and maintenance: Cooperative. Local university or community college. Funding: Government. NGOs.	Cooperative. Government.
	Reliance on external sources	High	Low	High	High	High
	Need for legislation	Very likely.	Not strictly necessary.		Very likely.	Very likely.
Focus on local socioeconomic development	**Workers' willingness**	Lack of willingness to reconvert.	Medium-High willingness to use the wire stripper.	Not assessed. Depends on the revenues.	Not assessed.	Low-Medium willingness to wear PPE. Medium willingness to displace.
	Operation and maintenance needs	Not applicable.	Low	High	High	High
	Training and capacity-building needs	High. Identification of new purchasers.	Low.	High.	High.	Low.
	Quality of copper*	Higher	Higher		Same	Same
	Quantity of copper*	Same or more.	Same or less.	More	Same	Same
	Affordability	Transport vehicles and equipment might be needed depending on the amount collected.	Low-cost tool for individual workers.	Expensive. It might be cost-effective if used by a group of workers.	Expensive. It might be cost-effective if used by a group of workers.	PPE might not be affordable for workers.

Table 3.4 Continued

ESCD criterion	**Option** **Factor**	**Elimination**	**Substitution**	**Engineering Controls**	**Administrative Controls and PPE**	**ESCD criterion**
Focus on local socioeconomic development	**Economic compensation*±**	Much lower. It can change if the market is intervened.	Depends on quantity. For the same quantity of copper, the compensation is higher.	Depends on the quantity and energy costs.	Probably lower because it incorporates additional costs.	Probably lower because it incorporates additional costs
	Time needed*	Less	Same or more.	Less	Same	Same
Efficient and careful use of energy, natural resources, and materials.	**Use of energy and materials**	Energy & Materials: None	Materials: Low (wood, blade, screws) Energy: None (operation)	Materials: High (machine) Energy: High (operation)	Materials: High (structure, filters, activated carbon) Energy: None	Materials: High (gloves, masks, glasses) Energy: None
	Environmental burdens	Risks of open burning are eliminated. Likely reduction of material being discarded.	Risks from open burning are eliminated. Plastic waste is generated if not sold.	Risks from open burning are eliminated. Plastic waste is generated if not sold.	Risks from open burning are reduced. Attempts against the circular economy.	Risks of open burning remain. Attempts against the circular economy.
Social Justice	**Allocation of rights, resources**	Industries might be benefited at the expense of urban recoverers and cooperativists.	Higher income and fewer risks might contribute to a better quality of life for workers.	Placing the machine at the cooperative might contribute to a power imbalance.	Placing the oven at the cooperative might contribute to a power imbalance. Other people will not be protected.	The continuous provision of PPE might create a high dependency on external sources.
	Impacts on human health	Risks from open burning are eliminated.	Risks from open burning are eliminated—new ergonomic and physical risks.	Risks from open burning are eliminated—new ergonomic and physical risks.	Risks from open burning are reduced for workers but not for neighbors.	Risks from open burning might be reduced.

*In comparison to burned cables ± No consideration of health & environmental costs

3.6 Conclusions

This chapter was intended to provide specific insights to promote successful occupational safety interventions with simultaneous potential economic benefits in two informal and semi-formal e-waste management Sites in Buenos Aires. It was demonstrated that the NIOSH Hierarchy of Controls can work as a framework to propose and analyze interventions. By extending a management model generally applied into formal occupational environments, this work allows us to recognize the multiplicity of factors that affect decision-making on risk management measures in contexts of high vulnerability and socio-environmental injustice. For example, an important consideration is that implementing the NIOSH framework in these e-waste contexts requires a thorough analysis of roles, the market, the materials, key partners and allies (e.g., recyclers federations, municipalities, academia), workers' willingness, previous knowledge, desires, work dynamics and potential impacts, and access to financing. Furthermore, the vision of the workers and main local actors has given us an understanding of the limitations and opportunities for its implementation. It is necessary to continue in this line of participatory work that respects the wisdom of formal and semi-formal workers and promotes alliances between stakeholders that have different perspectives but are looking at the same “problem.” We show that research and action are needed to respond to their demands for greater productivity, maintenance of jobs, and occupational safety. Other key messages from this chapter are 1) different interventions could be applied in such contexts, and all of them have advantages and disadvantages that are site-specific; 3) the preferred interventions are the ones that are more effective in protecting workers and their communities; 2) promoting safer occupational environments contributes to safer communities in general; 3) when it comes to training and awareness-raising, it is not enough to provide instructions, but to carefully analyze the possibilities for workers to apply them. The indications should be contextualized, sensitive to misconceptions, and prepared with options. 5) Building trust with workers is key to the success of interventions, hence, the messages from local authorities should not aim to scare workers but seek to provide them with “appropriate knowledge” to make decisions.

CHAPTER 4

INCLUSIVE URBAN MINING: AN OPPORTUNITY FOR ENGINEERING EDUCATION

Adapted from a manuscript under peer-review in *Mining*[32]

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4.1 Introduction

The first reference to urban mining is claimed to be in The Economy of Cities by the Urban Theorist Jane Jacobs in 1969 (Jacobs, 1969). In her piece, the author described future cities as mines with huge, rich, and diverse raw materials (Aldebei & Dombi, 2021; Jacobs, 1969). However, the origins of this concept are still under discussion (R. J. Grant & Oteng-Ababio, 2016) and differences in definitions arise based on the differing ideologies and priorities of stakeholders yielding the term.

In general, an “urban mine” is understood as the urban accumulation of anthropogenic materials aboveground (Aldebei & Dombi, 2021; Nakamura & Halada, 2015) and “urban mining” could be interpreted as the activity that converts “wastes” into resources (Chand et al., 2021). Aldebei & Dombi, (2021) understand urban mining as a metaphor for describing the same activities of prospecting, exploration, development, and exploitation as traditional mining. For the purpose of this article, we will utilize the following Cossu & Williams definition, “Urban Mining extends landfill mining to the process of reclaiming compounds and elements from any kind of anthropogenic stocks, including buildings, infrastructure, industries, products (in and out of use), environmental media receiving anthropogenic emissions, etc.” (Cossu & Williams, 2015) (p.1).

The term “urban mining” is assumed to be applicable to many kinds of waste. However, this work is based on two specific streams, namely construction and demolition waste (C&DW) and electrical and electronic waste (e-waste). These are two of the most relevant anthropogenic sources in terms of quantity and economic incentive (Ghisellini et al., 2022). E-waste mainly motivates research and practice because of the high concentration of rare earth minerals it contains, and buildings and infrastructure waste are the largest anthropogenic stock worldwide. In other words, C&DW is “the largest urban mine” (Aldebei & Dombi, 2021) (p.6).

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[32] Original manuscript submitted in March 2023. *Mining* is an MDPI Open Access Journal. This is an adapted version with minor edits by S. Schlezak that were not included in the original manuscript. Reprinted with permission of co-author J. Styer (Appendix B).

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As a direct consequence of the population growth, urbanization, and excessive consumption that characterize the last century, the exploitation of natural resources and the generation of waste have increased radically (Chand et al., 2021). Under these circumstances, the concept of urban mining of anthropogenic wastes has been introduced for almost four decades as an alternative to the conventional way of extracting raw materials, which is particularly important to decrease their depletion. For example, managing electrical and electronic equipment under the circular economy approach can reduce the use of raw materials to produce new devices up to 80% (Ghisellini et al., 2022).

Urban mining also serves as an approach to sustainable waste management in cities and can be a source of new job opportunities for young people and/or immigrants (Ghisellini et al., 2022). As an anthropologist studying informal e-waste management in Tanzania observed, "(...) recycling offers a skilled vocation, with a sense of stepped progression, secure revenue and entrance into a social support network that sustains and enhances local lives"(Ntapanta, 2021) (p. 7). Therefore, urban mining also has a potential to become inclusive by contributing to the production of goods and offering services while simultaneously pursuing social objectives to enhance the quality of life of vulnerable communities.

Although it is promising as an economic, social, and environmental activity, urban mining still has its limitations. At a global level, only about 18% of electrical and electronic equipment is treated in a sound environmental manner (Forti et al., 2021; Ghisellini et al., 2022), and about 35% of C&DW still ends up in landfills (Colorado et al., 2022). The causes of these figures have been studied in recent years. They include low recovery efficiency rates as a consequence of inefficient product design, lack of regulations and certifications to promote the use of reused materials, negative perceptions about second-hand materials and products, lack of awareness about the benefits of urban mining and the impacts of e-waste and C&DW, space scarcity in urban centers to store materials, high costs of best-quality recycling processes that make it difficult to afford for SMEs, and high competitiveness of landfilling associated to immature local markets and poor economic incentives for the circular economy (Ghisellini et al., 2022).

In Latin America, despite advances in this field, much work still needs to be done to improve the low waste recovery rates (Margallo et al., 2019). As a result, a significant part of the waste with economic potential is abandoned in open spaces (Aldebei & Dombi, 2021) or exported, resulting in lower efficiency of the waste management systems (Xavier et al., 2023). Furthermore, this situation limits green job opportunities in the region, especially for informal waste pickers and recyclers, who currently play a key role in the circular economy (Arain et al., 2022; Johansson et al., 2013).

In the last decade, many international organizations have been working on this topic and financial resources have been allocated in regional projects, e.g., the 2018-2022 UNIDO-GEF PREAL project for the Environmentally Sound Management of POPs in Waste of Electronic or Electrical Equipment

(Universidad El Bosque, 2021). However, projects and research are, in general, led by stakeholders interested in industrial ecology, waste management, environmental health, and the circular economy, rather than academics and researchers from the mining sector with interest in the potential of urban mining as an alternative economic activity of material extraction and social empowerment (Johansson et al., 2013).

While the traditional training of mining, metallurgical, and materials engineers might not be focusing on urban mining (Johansson et al., 2013), we agree that "shortly, our society is undergoing an accelerating transition from virgin mining of linear economy to urban mining of circular economy" (Zeng et al., 2022) (p. 104), and suggest these groups should be part of this transition. Johansson et al. (Johansson et al., 2013) claim that, as was the case for traditional mining and deep-sea mining, the development of technology could make urban mining attractive as an economic activity. They also highlight that even if the nature of mining changes, as any mining activity, engineers and researchers specialized in materials composition, collection, extraction, separation, and recovery are crucial to overcoming current technological challenges for implementation.

In light of the need for further research and initiatives, there is a potential for science and engineering education to contribute to these global challenges. Some scholars report a constant declining interest in mining studies worldwide (Adach-Pawelus et al., 2021) and proposed a focus on sustainable development to generate new competencies and subjects and promote innovative solutions and technologies by emphasizing environmental and social aspects (Adach-Pawelus et al., 2021). Literature has reported positive impacts from the incorporation of non-traditional mining areas into traditional engineering programs, for example, the case of incorporating artisanal and small-scale gold mining (ASGM) into the curriculum of an engineering college in the US (Lucena, 2020; J. Smith et al., 2021), an approach that was also recommended by organizations such as USAID and UNITAR as a crucial step towards formalization of the activity (DeJong, 2019; UNITAR & UN Environment, 2018). In this context, urban mining could be also proposed as an alternative to attract more students into the mining sector.

4.2 Objectives

Understanding that the mining industry is an important and necessary part of the production chain that should be aligned with international environmental agreements and goals, e.g., the United Nations 2030 Agenda and the Sustainable Development Goals, the future of mining must be sustainable and responsible when responding to the increasing material demands of the current and next generations. With this in mind, in this paper we illustrate how concepts such as inclusiveness and the circular economy can come together in new forms of mining–what we call inclusive urban mining–that could be beneficial to include in mining engineering curricula to see positive impacts in the mining industry as well as environmental and social justice efforts aimed at empowering vulnerable groups in regions such as Latin America.

Population movement from rural areas to urban centers has created increasing demands for employment, often for individuals with low levels of education and literacy (Carrillo, 2009; Cazabat & O'Connor, 2021; Ojeda & Donnelly, 2006). Under this context, cities play a role in offering stable, secure, formal, economically sufficient, and dignified green jobs, including in the waste management sector (Ghisellini et al., 2022). In this sense, we begin by demonstrating how, if recognized, inclusive urban mining could present an opportunity to benefit society across multiple echelons, including empowering vulnerable communities (Section 5.1) and decreasing environmental degradation associated with extractive mining and improper waste management (Section 5.2). To do so, we use our research experiences in the C&DW and e-waste sectors in Colombia and Argentina to show how present and future urban miners can be empowered to build livelihoods out of treating what is traditionally seen as waste and how their path could be extended to future miners. Then, recognizing that most engineering curricula in this field (e.g., mining, environmental, and materials engineering) do not include urban mining, especially from a community-based perspective (Section 6.1), we show examples of the integration of this form of mining in engineering education in first-, third- and fourth year design courses (Section 6.2). Finally, we conclude by providing recommendations for how to make inclusive urban mining visible and relevant to engineering education in different institutional contexts.

4.3 Description of the Study Sites

4.3.1 C&WD in Colombia

In the past decade, there has been a rise in research and literature on C&DW management issues (Yuan & Shen, 2011), and several countries like Germany, Spain, and Belgium are adopting strategies to treat and handle this waste (Pacheco Bustos et al., 2017). However, Latin America lags in this area, and some countries like Colombia, despite generating huge amounts of C&D waste, have not made noteworthy progress in managing it (Suárez-Silgado et al., 2019). Within a thesis project from 2003, author García Botero detailed C&DW in Bogotá, Colombia and examined if the sustainable development needs of the city are being met (García Botero, 2003). He concluded that approximately 99% of C&DW in the context of Bogotá is "useable" and a majority of this C&DW is made up of concrete, asphalt, brick, blocks, sand, gravel, earth and mud. Furthermore, Méndez-Fajardo's article argued that recycling and reusing C&DW can produce significant positive impacts for citizens; however, these potential values are often overlooked (Mendez-Fajardo, 2011). These positive impacts can be seen at multiple echelons including the environmental, social, cultural, economic, and even political level.

To study how to promote and support inclusive C&DW management in Colombia for the empowerment of low-income communities, we worked with Community A, which is a small, low-income community located just outside Girardot in the department of Cundinamarca. Girardot is a popular vacation spot and houses many recreational activities due to its warmer, tropical climate and close proximity to Bogotá, the capital of Colombia that is home to over seven million people.

Unfortunately, not much is officially known about Community A. Based on our estimates, about 200 families live in the community, many of which do not have access to sewage systems. This site was considered relevant for the study because of their desire to take part in the project as well as the occupational profile of the inhabitants. While many of the men in the community work in construction practices, most of the women work in the informal sector (selling products such as soda, avocados, arepas, etc., from their homes or on carts either in the city or on the roads surrounding it) or are unemployed. Furthermore, despite their occupational status, all the women in Community A are caretakers in their homes as well, for their children, parents, pets, and households. The local knowledge and the gender-related disparity in terms of job opportunities made Community A an interesting case to study inclusive urban mining. The members in the community we spoke with wanted to learn how to extract value from C&DW and how they could make it profitable for themselves and their families. Thus, the goals of this project were refined with the guidance of the community, to increase education about C&DW and find a way to make this effort profitable.

4.3.2 E-waste in Argentina

Despite the fact that Argentina has the second highest annual generation of e-waste per capita of any Latin American country (Wagner et al., 2022), the management of this waste stream is considered an emergent activity in the country, and little is known about it. Recent reports developed by national authorities confirmed that there is a data gap (Maffei et al., 2020), and the lack of regulations reveal that electronic waste management is a pending issue in the country. However, there are communities whose income depends on these materials. Some sources estimate that in 2017, nationally there were 600 people working in the informal e-waste recycling sector, and the number grew to around 2,000 workers in 2019 (Maffei & Burucua, 2020). A different source indicated 2,800 workers in 2019 in only 14 municipalities in the province of Buenos Aires (Maffei & Burucua, 2020).

The province of Buenos Aires and the City of Buenos Aires were selected as study sites in Argentina because they agglomerate the largest population and contain the enterprises and cooperatives that process the highest amount of e-waste (Maffei & Burucua, 2020; Wagner et al., 2022). To address the topic of inclusive urban mining, four cooperatives were studied. Cooperatives are “autonomous associations of persons united voluntarily to meet their common economic, social and cultural needs and aspirations through a jointly owned and democratically controlled enterprise" (*Recommendation R193 - Promotion of Cooperatives Recommendation, 2002 (No. 193)*, n.d.). Three of the cooperatives under study are exclusively dedicated to e-waste, and one is a cooperative dedicated to solid waste but brings together workers who individually recover e-waste materials. Additionally, we included one university extension program that is currently offering e-waste management services in the province. The names and specific details of these facilities are protected, so they cannot be easily recognized.

- Facility A (cooperative): It started in 2018 as a solid waste cooperative, and since 2022, its members have decided to explore e-waste processing as an additional source of income. The e-waste sector now has five workers and one coordinator. They are in the process of formalizing their activity in relation to e-waste management.
- Facility B (cooperative): It is a solid waste cooperative that started almost 10 years ago. They have more than 150 members, and almost half of them individually recover e-waste material from the streets. The cooperative is interested in e-waste, but its members do not have experience with this waste stream yet.
- Facility C (cooperative): With almost 20 workers, this cooperative is one of the province's most advanced small social businesses. They have already obtained legal permission to manage e-waste, which is their main activity.
- Facility D (cooperative): It has more than 20 years in the business and employs more than 25 workers. The cooperative is recognized as a formal e-waste operator and treats almost 1,400 tons of waste per year.
- Facility E (University extension program): This began as an academic extension program and now is one of the few e-waste operators in the province. Since 2009 they have trained 1168 students and treated 217 tons of e-waste.

4.4 Methods

4.4.1 Participatory Framework and Ethical Considerations

As the local knowledge of communities is crucial for developing sustainable and just solutions (Ottinger, 2011), our research methods were participatory and took a qualitative approach to understand the neglected knowledge, expertise, and values of the communities they work with, as well as the complex systems that shape their lives. Qualitative methodologies such as semi-structured interviews, participant observation, focus groups as well as workshops were utilized to build this understanding. Both projects were approved by the Colorado School of Mines Human Subjects Review Team and exempted from Institutional Review Board (IRB) process requirements.

The research in Colombia was developed in partnership with a Colombian university, Corporación Universitaria Minuto de Dios or Uniminuto. The groups specifically working on this project were the Parque Científico de Innovación Social (PCIS)/ the Social Innovation Science Park, a research group led by Civil Engineering and Occupational Health and Safety Professors with social justice aims entitled Ingeniero a tu Barrio, the international studies group in Uniminuto-Girardot, as well as communication specialists including Professor Martha Liliana Herrera Gutiérrez, who was essential for translation, facilitation, and communication. Together we worked directly with a low-income community in Colombia, Community A, to study how recycling C&DW, and specifically concrete, could empower them. Approval for this research was also obtained from local Colombian authorities, including Uniminuto's PCIS as well as their research ethics committee. Additionally, the research in Colombia adheres to Uniminuto's Social Innovation Route Framework (Pacheco Duarte et al., 2021), a five-phase community engagement framework developed by PCIS.

4.4.2 Semi-structured Interviews

Throughout the six weeks of fieldwork on C&DW completed in Colombia during June and July 2022, we interviewed 17 women and 12 men all from differing backgrounds, including low-income community members, community leaders, engineers, academics, students, waste management experts, and government officials. During each interview, translation services were provided by professors from Uniminuto. Within these interviews, we asked our interlocutors to describe their backgrounds, knowledge of concrete and C&DW, risks and barriers they believed could prevent recycling C&DW in low-income communities, and if any groups could be disproportionately affected by these risks. Additionally, as this project has specific social justice goals to contribute to women's empowerment in low-income communities, our focus was to speak mostly with women in the community to understand their interpretations of women's empowerment and define how they specifically wanted this project to empower them.

A series of exploratory interviews were carried out during June and July 2022 for the research on e-waste. A total of 15 government representatives, researchers, and members of e-waste cooperatives and programs were interviewed. The meetings, each lasting approximately one and a half hours, were held virtually. The interviews were aimed at obtaining preliminary information on the current situation of e-waste management in Argentina, with a particular focus on the province and the city of Buenos Aires. Participants were asked to describe their workplaces, e-waste-related practices and dynamics, the challenges that the sector is currently facing, and their opinions on past and current waste management strategies.

Additional non-recorded interviews with e-waste workers and governmental officials were conducted during the participatory observation visits described in the next section.

4.4.3 Participatory Observation

Upon the beginning of our fieldwork session in Colombia, the Uniminuto team began facilitating meetings with Community A right away. As the Uniminuto team had already worked with this community in the past, many community members already knew most people on our team. However, it was essential to build rapport with the community during these meetings for the group members who had not had the opportunity to work with Community A previously. Thus, time was spent introducing ourselves and our goals and having conversations with community members. To understand the community's goals for this project, it was important to understand the context of the community, their values, beliefs, journeys, destinations, language, knowledge, and more through participant observations. We spent a lot of time trying to understand the knowledge community members had about C&DW and recycling and learned the community was already utilizing C&DW in their homes and on shared roads but in unsustainable ways. While there is a Junta de Acción Comunal for the community (a legally protected organized civil structure made up of members of the community), there are also natural leadership structures and leaders as well. Despite this divide in power structures, both groups wanted to find a way to make this effort of recycling C&DW profitable and beneficial for the community. The understanding of these relationships contributed to the understanding of urban mining potential in the community.

In Buenos Aires, jointly with representatives of two local government agencies, three visits to e-waste facility A and two to facility B were carried out in August 2022. In facility A, the researcher was accompanied by a team consisting of one toxicologist and three social workers, and in facility B an environmental professional led the visit. Three other e-waste facilities in the province of Buenos Aires were visited by the researcher. During these encounters, neither video nor audio recordings were made. Photographs of the workspace, machinery, devices, and waste were taken with the previous authorization of participants. The objective of the observation was to understand the different contexts of e-waste workers, their work dynamics, power distributions, needs, concerns, and desires. These interactions helped identify new actors and refine data on materials and equipment, collection and treatment practices, and the value chain characteristics.

4.4.4 Workshops

Through preliminary analysis of the data gathered on C&DW during interviews and participant observations, a common theme we noticed was the desire of bringing educational opportunities to the community and doing workshops to give community members, especially women, skills to generate income. To follow our commitment to a community-centered research approach, we are developing a participatory workshop to take place with Community A in March 2023. This workshop should present an opportunity for women and low-income community members in Colombia, specifically targeted towards Community A in this approach, to engage one another in the process of learning about recycling concrete from C&D waste and develop a plan for how this can become actionable in their community. So far, while designing this workshop, we have outlined 4 key components we think may be necessary to include: C&D Waste Composition and Values; C&D Recycling Processes and Technologies; Environment, Health, and Safety; and Applications and Entrepreneurism. However, we are working with community members through virtual communications to ensure these components are necessary and determine if they want anything else to be included.

For e-waste communities, two workshops were held with each group of workers from facilities A and B. The main objective of the workshops was to analyze workers' perceptions regarding the chemical risks related to their activity, train them in basic concepts of risk prevention and management, and collect their opinions on a proposed intervention to prevent the open burning of cables. All the e-waste workers at facility A (five, males) participated in the workshop with their coordinator (one, male). At site B, since the cooperative is not formally working with e-waste, the associated urban recyclers with e-waste experience were invited to participate. In total, 37 (17 females, 20 males) and their coordinator (one, male) participated in the workshop. The activities were conducted in two hours and included: 1) Initial general risk identification activity, 2) E-waste risk perceptions activity, 3) Discussion about a cable stripper prototype, 4) Community mapping of burning sites, metal buyers, and collection points (only at site A). Audio recordings were taken with prior permission of the participants.

4.4.5 Research Extension with Colorado School of Mines Undergraduate Students

Following the teaching philosophy of the Colorado School of Mines (CSM) Humanitarian Engineering and Science program (Lucena et al., 2022), three graduate-undergraduate research extension activities were carried out with CSM undergraduate students. First, the topic “Empowering People: Extracting Value from Waste Through Urban Mining” was proposed as project motivation in the “Design I” course in Fall 2022, aimed at more than 600 first-year engineering students. Second, for a senior design course, specific sociotechnical challenges related to C&DW and e-waste were proposed to the students. Third, a new version of the “Engineering and Sustainable Community Development” course was delivered to 24 undergraduate students in Spring 2023, based on three e-waste technical challenges defined by a community of recyclers in Bogotá, Colombia.

4.4.6 Preliminary Review of Mining Engineering Curricula

To describe the approach of urban mining and inclusive urban mining as topics in engineering curricula, we conducted preliminary research on curricular databases from universities in the United States. We selected the top universities in mining engineering, as listed on the National Mining Association website (“Mining Schools and Universities,” n.d.), then we examined each university’s website and/or online course catalog individually, solely looking at their minimum requirements for obtaining a Mining Engineering Bachelor of Science in the 2022-2023 academic year. University, general education, and B.S. course requirements were not included. When examining each catalog, we searched each course description to determine if urban mining concepts and sociotechnical approaches were explicitly stated as learning goals in required courses. To search for urban mining concepts, we utilized the following search terms: “urban mining,” “construction and demolition waste,” “C&DW,” “electronic waste,” and “e-waste.” We also searched for sociotechnical learning approaches by searching for the terms “community,” “sociotechnical,” “social,” “societal,” or “human.” Understanding the limitations of this approach because of its subjectivity related to the lack of detailed information describing the material reviewed within the required courses as well as the research projects being conducted within these universities external to course curricula, we incorporated our findings as a preliminary set of data that could be further analyzed in future works.

4.5 Inclusive Urban Mining in Latin America

Currently, in most Latin American countries, the “resource recoverers” (Gutberlet, 2009) or, as we refer to them in this paper, “urban miners,” are not yet integrated into the regulatory framework, and their working conditions are often precarious, exposing them to hazardous chemicals, including heavy metals and halogenated compounds (Deng et al., 2014). Although they provide a key environmental service, waste workers have also been historically stigmatized and excluded within society (Gutberlet, 2009).

With growing interest, but still minor in comparison with traditional mining, some countries in the region are facing the challenge of regulating the activity of urban mining, integrating informal workers, and promoting improvements in processes and technologies to increase productivity and promote sustainable local economic development [31,32].

To help overcome the challenges and barriers enumerated, below we present current and potential benefits of urban mining for communities and the environment with special focus on Latin America. These are supported by our literature research and experiences with communities in Argentina and Colombia interested in treating waste not only as a source of income but also as a way of empowerment. This is how we introduce the concept of inclusive urban mining, a concept that has its roots in the inclusive solid waste management, an activity with a long history in these two countries (Gutberlet, 2008b; Gutberlet & Carenzo, 2020).

4.5.1 Why Should Urban Mining be Inclusive? Some Examples of Its Social Benefits

4.5.1.1 Women's Empowerment: Through Recycling C&DW

When asked about their role in their community, household, and workplace, many of the women in Community A in the Colombia research claimed to be a leader of some kind. Whether they defined that as having a position of power and knowing they could tell others what to do, or as a mentor or friend people came to when they needed something such as advice. Some cited their age here too when asked about their role, stating that because they are older, they are wiser and therefore better leaders. When asked about the problems women face in their community, problems with children were often cited such as children being left alone or turning to illegal activities to make money. Another problem that often came up was unemployment, sometimes due to the lack of transportation or job opportunities. Finally, when asked about solutions to these problems, and how the term women's empowerment was understood, people often brought up workshops that had taken place in the community in the past. These workshops often focused on cosmetology such as doing hair and nails, art practices, or even baking or cooking. Many people brought up education and the importance of learning, and some brought up making money and having the ability to secure and spend money for themselves or their family while in the confines of their own homes.

One morning in mid-June, we had the privilege to speak with Peggy, one of the natural leaders of Community A. We were lucky enough to work with Peggy on this project and spent a lot of time on her porch, doing interviews with community members, meeting and talking with her family, or observing how the community naturally operated. We talked about her family, how she came to Community A, what she thought about the project, and what she was hoping for, especially for the women in the community. When asked about women's empowerment, she stated, “[Women's empowerment] is the idea that women can work on their own with their own capacities.” Bringing up examples such as doing their own nails or making their own clothes. Peggy brought up the importance of bringing opportunities to the community and doing workshops to give women tools to find jobs.

As illustrated in the semi-structured interviews conducted with women in Community A, in this context it was found that urban mining can best empower them through generating more income and increasing education to gain additional skill sets. While financial and economic decision-making power is a common dimension of women's empowerment, the details of how exactly this pursuit could be more beneficial and empowering to women in Community A was developed through a dialogue and an understanding of the context of the community. For example, the women demonstrated the need for the time and capacity to care for their families alongside these pursuits, thus making this a homebound endeavor.

While urban mining shows promise to contribute to empowerment opportunities for multiple vulnerable groups including women, it must be acknowledged that these contributions can be maximized through a contextual understanding of the complex systems that shape the lives of these groups. As such, there is a need for academic institutions, especially those related to engineering and design, to work alongside communities to understand how pursuits such as urban mining can empower them. Moreover, to ensure relevant empowerment to vulnerable groups, it's essential to take an interdisciplinary approach, as empowerment is contextually situated, thus different ideas of empowerment exist within different contexts and are reflective of their own specific communities and cultures.

4.5.1.2 Social Transformation and Digital Inclusion in the E-waste Sector

In our visits to e-waste facilities, we observed the pride of workers about their role as green actors in a context where circular economy policies and regulations, although necessary, are still pending. This role is one of their motivations when facing the many obstacles presented to them. To name a few, they have little bargaining power vis-à-vis buyers –mostly intermediaries– and limited access to information and technologies to maximize waste recovery. Even with all the challenges, these groups of workers, mostly born and raised in vulnerable conditions, go through a collective process of what they call “subsistence, resistance, and transformation.” Some are young adults who have never kept a job for more than a couple of months, but in their cooperatives, they become resilient and learn not only specific knowledge relevant to their business, but also the general rules of the labor industry, such as complying with the schedule and attendance. Hence, as an interlocutor told us once, “We [the cooperative] not only recycle materials, but people.” Therefore, it is not arbitrary that some cooperatives have included words like “dignity” or “justice” in their names. We see, then, that the feeling of belongingness that the activity generates in workers has the potential to contribute to the education on labor conduct, becoming a transforming process for some young recyclers.

For workers in general, as in any other labor space, learning new skills and developing new knowledge are essential instances, and urban miners are not exempted from this process. They learn to repair and disassemble e-waste by gaining specific knowledge about electronics, IT, mechanics, and sometimes material composition and chemistry. However, particularly for this sector and especially in the Latin American context, learning these disciplines goes beyond training workers in their roles. This learning process also means a step towards their insertion in an increasingly demanding digital society. This is an additional benefit of urban mining, illustrated by the case of a worker who, during a workshop, told us, "Since they [the cooperative] gave me a computer, I was able to use one for the first time in 60 years." This worker's access to technology, although based on the objective of training him in electronics repairing, ended up meaning his access to a digital world that is often hampered for people his age.

In urban mining cooperatives, we have experienced some examples on how not only materials but also people are transformed. Understanding this opens the way to a huge number of study areas that are scarcely explored today by the academic community. We question, what other social benefits do urban mining cooperatives bring? Could the social benefits be externalities that account for the comparison between urban mining and traditional mining? We wonder, in particular for the e-waste management sector, how could actors dedicated to digital inclusion and actors dedicated to e-waste management interact? What impacts would a more inclusive digital society have on the use, disposal, and management of electrical and electronic devices? Could the circular economy based on e-waste become a mechanism for digital inclusion?

4.5.1.3 The Value of Local Knowledge for the Global Development of Urban Mining: Examples from the E-waste Sector

Although many of the e-waste recoverers did not perceive themselves as producers of knowledge or technology, as a result of our visits and workshops, we learned that these workers' knowledge is as important as any other certified by an academic degree. For example, some of them quickly identify components and materials with high efficiency, and some apply craft and ingenious low-cost plastic identification methods (e.g., by their texture, smell, or color). Others have perfected techniques, such as manual disassembly or burning, to improve the quality of the metals they obtain. Likewise, some workers with long experience in the sector have undertaken the important task of sharing their knowledge with less experienced peers, providing in-person training and written material. The information is exchanged between the workers themselves. They themselves are the referents of the activity and share their knowledge. A good example is the free and public guidance document "Cooperación y reciclado para un mundo sustentable" ("Cooperation and recycling for a sustainable world") edited by Salcedo et al. in 2019 (Salcedo et al., 2019).

In the literature, waste workers are usually pigeonholed into informality (Carenzo, 2017), and under a global gaze that proposes external strategies to deal with local problems. We believe that to avoid the traditional labels of "lacking" or "informal," and put an end to the historical marginalization of the recyclers, waste pickers, and waste workers in general, it is necessary to study their resilient learning, improvement, and knowledge-transfer processes. Johansson et al. (2013) claim that "the informal sector can nevertheless teach us how to change our perception of technospheric stocks and view them not as a problem but as a resource" (p. 42). We wonder, thus, how their voices could be amplified so that larger audiences know how their inventiveness and persistence can serve to overcome the barriers of the context in which they work, and how these skills and knowledges can contribute to the global challenge of e-waste, C&DW, and other relevant waste streams. We ask, then, what can Latin American urban miners contribute to the global conversation on waste management? How can local knowledge improve foreign technological processes? These proposals are not in opposition, but on the contrary, they seek to promote a synergistic interaction between the development of knowledge and technologies in Latin American countries and countries from other regions.

4.5.2 Environmental Benefits of Urban Mining

Present-day demand for material resources combined with concerns about the sustainability of extraction practices and the effects of waste have increased interest in both practitioners and scholars in the concept of the circular economy. In this context, urban mining is gaining momentum from various perspectives (Koutamanis et al., 2018). First, this practice rejects linear approaches to production, instead replacing the “end-of-life” stage of traditional waste management with reusing, recovering, and recycling processes throughout a product's life (Kirchherr et al., 2017). Second, many scholars agree that urban mining improves resource fulfillment by advancing the circular economy and also minimizes the environmental burdens (Lopes dos Santos, 2022). Obtaining materials from discarded items can also contribute to climate change mitigation since metal recovery consumes less energy than the extraction of primary raw materials (Lopes dos Santos, 2022). For instance, the energy needed for the manufacturing and transport of building materials could be reduced by about 29% if these materials are recycled (Blengini, 2009; Ghisellini et al., 2022; Thormark, 2006). Third, urban mining provides a solution for uncontrolled waste management, which remains a significant global challenge (Margallo et al., 2019) due to factors such as the exposure of the environment and humans to hazardous substances and biological vectors. The accelerated growth of waste on a global scale results in valuable aboveground stocks in quantities that are often comparable to or exceeding natural stocks (Cossu & Williams, 2015). For example, Grant et al. (2016) indicate that “thirty smartphones contain as much gold as one ton of mine rock from a traditional gold mine” (p. 7). Thus, these resources have become attractive to those that acknowledge the gradual depletion of economically mineable resources (Koutamanis et al., 2018).

4.5.2.1 Environmental Benefits of Recycling C&DW in Colombia and E-waste in Argentina

The construction industry is a main contributor to carbon dioxide emissions across the globe due to it containing many elements with high carbon footprints such as cement and concrete production, transportation, as well as C&DW generation (Akhtar & Sarmah, 2018). In 2020, the United Nations Environment Program (UNEP) stated that the buildings and construction sector accounted for 38% of the total global energy related CO2 emissions in 2019 (UNEP, 2020). The cement industry alone contributes to about 8% of the global CO2 emissions (Andrew, 2017). Effectively managing C&D waste is a critical component of preserving our environment, natural resources, economy, society, etc. (Kabirifar et al., 2020). Despite this, C&D waste mismanagement is a widespread issue.

Around the world, the problem of C&D waste is worsening, and it is exacerbating environmental and social challenges alongside population growth and urban expansion (Francisco et al., 2019). In Colombia, the construction industry's expansion is aggravating these issues by disposing of C&D waste in an insufficient and unregulated manner, and by increasing illegal extraction of aggregate materials (Bravo-German et al., 2021). These increasing environmental and social issues are leading to national recognition in Colombia, as seen in Resolution 472, which outlines the management of C&D waste in Colombia in light of the inadequate disposal and increased generation of C&D waste in cities across the country including Bogotá, Medellín, Santiago de Cali, Manizales, Cartagena, Pereira, Ibagué, Pasto, Barranquilla, Neiva, Valledupar and San Andrés (SAS, 2017) as well as other legislation released over the past couple years (Granados Santos et al., 2019; Ministry of Environment and Sustainable Development of Colombia, 2021; Ministry of Environment of Colombia, 1994). Recycling C&DW could contribute to reducing the inadequate and unregulated disposal of C&DW. Furthermore, it can decrease the illegal extraction of aggregate materials.

Some national reports estimate that, in Argentina, 465,000 tons of e-waste are generated per year and only 4% is managed in an environmentally sound manner (Maffei & Burucua, 2020; Wagner et al., 2022). Roughly, following the methodology in Forti et al. (Forti et al., 2021), we calculated that this low percentage contributed to a net saving of eight kt of CO2, equivalent to emissions from the recycling of secondary raw materials substituted to virgin materials. If this percentage increases up to the goal of 30% under the Target 3.2 of the ITU Connect 2030 Agenda (International Telecommunication Union (ITU), n.d.), it might help save up to 60 kt of CO2 equivalent emissions.

4.6 Inclusive Urban Mining in US Engineering Curricula

4.6.1 Preliminary Screening of Urban Mining Content in the US Engineering Programs

Table 4.1 summarizes the findings of the preliminary research on curricular databases from universities in the United States with Mining Engineering Bachelor of Science programs. There are 13 universities in the United States with Mining Engineering programs. Within these programs, urban mining was not explicitly listed as a learning goal in any of the course descriptions found within the universities’ websites and/or online course catalogs depicting the minimum course requirements for obtaining a Mining Engineering Bachelor of Science in the 2022-2023 academic year. Some programs seemed to include courses with sociotechnical approaches, or at least discuss human-based concepts in some way, however, these approaches were typically found more often within non-required courses.

Table 4.1 Preliminary Review of Mining Engineering Curricula related to urban mining and sociotechnical learning approaches in the US.

	University												
Number of Required Courses	1	2	3	4	5	6	7	8	9	10	11	12	13
Urban Mining Concepts	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociotechnical Concepts	0	2	0	1	0	1	0	4	3	1	0	0	0
Number of Non-Required Courses	1	2	3	4	5	6	7	8	9	10	11	12	13
Urban Mining Concepts	0	0	0	0	0	0	0	0	0	0	0	0	0
Sociotechnical Concepts	1	3	3	2	0	2	0	4	3	1	0	0	1

Search terms: “urban mining,” “construction and demolition waste,” “C&DW,” “electronic waste,” “e-waste,” “community,” “sociotechnical,” “social,” “societal,” “human.”

To reiterate, our findings should be viewed as a preliminary set of data that could be further analyzed in future works due to the limitations of this approach, including its subjectivity related to the lack of detailed information describing the material reviewed within the required courses in course descriptions found on university websites. Additionally, this screening did not include research projects being conducted within these universities external to course curricula.

It is not the intention of this work to only focus on the US curricula but to call on global engineering and technology academic institutions to involve current waste management challenges in their programs as motivators for technological innovation projects. With the examples described below, we want to emphasize that urban mining could represent a research subject and an educational opportunity for organizations specializing in traditional mining, taking advantage of their existing technical knowledge in material extraction and processing.

4.7 Approaches to Include Urban Mining in US Engineering Curricula

4.7.1 Introducing Urban mining to First-year Engineering Design Courses

The faculty in the design 1 and 2 courses at CSM are diverse in terms of academic and professional backgrounds. They mostly have STEM majors, such as design, civil engineering, electrical engineering, and other traditional engineering disciplines. Some have experience in the industry, and some others are senior researchers. This diversity gives the students exposure to different industries and “real-world problem-solving and design experiences,” as our interviewee claimed. In total, they teach 25 groups of 25 first-year engineering students by applying an ambitious but enriching approach involving problem formulation, design thinking, and stakeholder engagement.

The purpose of their teaching approach is to expose students to stakeholders and communities they did not know about and to make them reflect on how those people are going to be impacted by their projects. Its purpose is also to broaden students' perspectives in ways that they might never find out on the news or social media. This approach is not exempt from resistance, either from Faculty or students. According to the instructor, many students tend to separate the technical and the social and only focus on the technical challenge because, in the end, “the majority is going to end up in traditional engineering jobs one day, and that is just the path they want.” Some other students understand the complex issues that low-income communities are facing, but they just do not want to get involved. In this context, the instructors try to emphasize the importance of integrating knowledge. The faculty is clear when they explain to students that engaging with stakeholders and considering the specific contexts, geographies, cultures, and expectations are key stages in the design process. “You can't do technical in a vacuum,” our interviewee claimed. As an example, he asks students, “Could you design a technical solution without considering government regulations?”

The efforts of going beyond the boundaries of traditional engineering are huge for the faculty, and in spite of some room for improvement in terms of genuine stakeholder engagement, those instructors that have traditional engineering backgrounds are proud of what they are doing in this class. They are aware that even if it is an introductory course, they provide different additional techniques that are not offered in the first year in other programs in the US.

At CSM, students receive a “call for proposal” (CFP) broad enough so they can elaborate on the problem after a series of research stages that can involve literature research and consultation with subject experts, potential users, and other stakeholders. In 2022, for the very first time, the CFP was developed in collaboration with two graduate students from the Humanitarian Engineering and Science program—authors of this paper—. The topic, “Empowering People: Extracting Value from Waste Through Urban Mining” was innovative since it introduced urban mining, life cycle, and waste management as motivations for design. The students received a brief description of the general situation of waste management systems in low-income communities and the specific challenges and opportunities in the study sites we present in this paper.

The way the CFP was developed gave students the opportunity to set the boundaries of the problems by themselves, encouraging them to think creatively and "out of the box," to look at things outside their own immediate context, and to familiarize with the processes that happened after "the magic truck comes by and picks up the purple bin."

From a total of approximately 625 students, 110 students grouped in 25 teams achieved the 20% best-scored projects. Among the winning teams, the distribution of themes was Food/organic waste (5), E-waste (4), Plastic/packaging waste (4), Household effluents (2), Medical waste (2), Textile waste (2), and Others/Out of scope (6).

The CFP motivated students to reflect further down the line at the end of product life. For example, some students worked on recycling technologies to be applied locally. Some others looked at extending the life cycle by redesigning products or tried to look for upcycling opportunities at the source. A number of students preferred to address the specific challenges related to the settings and contexts that we have presented. They usually choose their path according to what they are exposed to and tend to lean towards stakeholders that they already know. The groups interacted with recycling, electronics, and processing companies, big warehouses, consumers, and professional users.

Although the experience was enriching for both students and professors, introducing the idea of a new way of mining provoked some tensions in a school well-known for its mining tradition. Some mining professionals asked, "Why are they calling this mining?" and claimed "This is not our definition of mining. This is not what mining engineering is." We wonder, then, what does it take for the traditional disciplines to extend their boundaries? In the end, changes in the curricula that in the past seemed far off, such as the inclusion of the social aspects in a first-year engineering design course, became a reality seven years ago. We wonder, what is urban mining lacking to be considered as a topic of relevance by the traditional mining sector? What are the differences? What are the convergence points?

4.7.2 Introducing Urban Mining in Elective Courses: The Case in an Engineering and Sustainable Community Development Course

For the very first time, in Spring 2023 the course Engineering and Sustainable Community Development (ESCD) was taught in a project-based format, involving direct interaction with communities. This course gathers twenty-five third year and graduate students to collaboratively work with a Colombian recycling association with the goal of improving three processes: e-waste plastic identification, copper separation from cables, and precious metals separation from circuit plastic boards. From the instructor's perspective, urban mining is not the initial motivation of students that join this course. These students care about community-based projects in general, and, even if they have education in specific disciplines

(Environmental Engineering, Civil Engineering, Mechanical Engineering, Chemical Engineering, and Design Engineering), they are curious about the many different ESCD opportunities for practice. Addressing a waste-related topic and how other communities interact with it stimulates students to think in a way that they never have.

According to the instructor, urban mining could be clearly framed as the future of mining. He thinks it has the potential to convene students, researchers, and industry professionals who are not usually involved in traditional mining (for example, electrical and civil engineers) that would be able to apply their knowledge and skills to transform anthropogenic waste stocks into valuable materials. In this sense, traditional mining institutions could see urban mining as a way to expand their curricula, staff, and areas of expertise. The expansion, however, will not be easy for those that have a traditional mining background, he said. It will require not only their willingness but the apprehension of new knowledge to deal with mines not located in the mountains but in the cities. Therefore, the challenge ahead will be to deal with the technical differences as well as the intricate relationship between material extraction and urban systems.

When we asked him about how to make urban mining visible and relevant, the instructor did not hesitate to claim that extending graduate research into first and third-year design courses is an important grassroots step that could eventually position the topic as an institutional priority from the top-down. He explained that improving urban mining does not only contribute to the circular economy but also provides employment opportunities for marginalized groups of people, such as the ones displaced by violence, poverty, or climate change. In this sense, applying a community-based approach in the engineering curricula gains more significance when urban mining is seen as an employment solution. He acknowledged that engineers could address urban mining from an industrial, automated, and large-scale perspective, but in doing so, they might be ignoring and neglecting the current labor problems that cities are facing, and the minor waste streams that are managed in small neighborhoods. “All those stocks of waste are always going to exist, and all those people needing employment are always going to exist irrespective of the big machinery that you put in place.” Hence, he emphasizes the need for more engineers and engineering students to be trained to co-work with marginalized communities with the aim of improving their processes, products, and labor conditions.

Some parallels between artisanal small-scale gold mining (ASGM) and urban mining are important for the instructor to point out. Less than one decade ago, the Minamata Convention forced countries to focus on mercury, and ASGM became a major area of interest for many institutions, including well-known traditional mining schools and research centers in the Global North. This new area of interest opened opportunities for research and practice in fields like engineering and social sciences. The recurrent presence of informality and the way in which communities engage in these activities, sometimes ending up exposing them and their families to hazardous chemicals, are other points in common between ASGM and urban mining. Furthermore, ASGM and urban miners both “are for the most part invisible to mainstream society,” the professor said. In this sense, we wonder if similar drivers, such as the global concern about scarce materials such as rare earth elements, metals, and minerals, might have the same result for urban mining. Will inclusive urban mining become a field of research and practice in the way that artisanal scale gold mining did, even with the tensions and resistance that it generates?

4.7.3 Introducing Urban Mining Projects in Third and Fourth-Year Project-Based Design Courses

In an effort for upper-level engineering students to learn more about human-centered design and humanitarian engineering challenges, a three semester hours project-based design course targeted towards junior- and senior-level students is offered at CSM. Within the Fall 2022 semester, multiple graduate students from the Humanitarian Engineering and Science program—including the authors of this paper—were able to work with project teams in this course on specific real problems affecting real people. Overall, of the 23 students registered for this course in the Fall 2022 semester, 10 students worked on urban mining-related projects. One group of four students worked on a C&DW-related project while two groups of three students were devoted to e-waste-related projects.

The faculty member responsible for facilitating the course in the Fall 2022 semester described urban mining as an opportunity, not only to “emphasize reclamation of precious materials in environmentally friendly ways that are also economically beneficial to disadvantaged populations” but to push back on the negative connotation associated with the term “mine” due to the often-harmful activities, practices, and ramifications of the industry. The professor believes urban mining is a way to “reclaim the word ‘mine’ for positive applications”, and institutions responsible for the progression of the often-damaging activities, practices, and ramifications of traditional mining processes, such as universities including CSM, should be at the forefront of developing “more environmentally friendly and socially equitable ways of mining and engineering”, such as urban mining. In conjunction with the responsibility to include urban mining in curricula to atone for the negative externalities involved in traditional mining, the inclusion of such a novel topic in traditional mining engineering curricula can also be an opportunity to enhance mining engineering education by facilitating understandings of concepts such as life cycle analysis.

In addition, the professor stressed the importance of understanding the local context of projects, such as the cultural, socioeconomic, and environmental dimensions of the cities in which they work with, and utilizing approaches from the social sciences and environmental sciences to develop solutions that are “most appropriate to their target population and do the least harm to the same population as well as their environment.” He stated that this utilization and understanding was even more essential than technical foundations, such as the engineering mindset, to arrive at a point where the technical solutions were appropriate. Furthermore, to develop the best solutions possible, the professor argued that stakeholder engagement, particularly empathetic stakeholder engagement ("which is culturally sensitive, appropriate for local contexts, aware of potential unintended consequences, and ultimately in search of the greatest number of 'win-win' situations as possible, where the environment is also a key stakeholder"), is essential. We question then, how important social and environmental science approaches can have a space in engineering curricula? As these topics (particularly the social sciences), despite their importance, are traditionally shunned in engineering education.

4.8 Conclusions

As was illustrated above, urban mining has a leading role in the circular economy as it is currently framed. But in particular contexts, such as in Latin American countries, this activity poses additional benefits that can be maximized if they are understood and studied. We state that the study of urban mining from an interdisciplinary approach could contribute to this field to achieve a much more inclusive and sustainable activity.

For urban mining, the cities are the locations where the extraction, circulation, and accumulation of materials take place. Hence, to favor inclusive urban mining it is not only necessary to understand collection and extraction processes but also to understand cities and their context. Contextualizing this activity means analyzing local legal frameworks, stakeholders involved, their history, ideologies, culture, alliances and power differentials, the flow of materials, current technologies, and processes. In light of our findings, we argue that the future challenges associated with inclusive urban mining are sociotechnical in nature. Thusly, we highlight the importance of promoting community-based research methods and concepts from the Engineering and Sustainable Community Development practices (Lucena et al., 2010) to be included in mining, materials, metallurgical science, and engineering academic programs as a way to address these challenges.

It is not without reason that we have argued the case for working alongside communities to solve problems in a participatory way as the local knowledges of community members is crucial for developing sustainable and just solutions. However, this effort makes it necessary to promote knowledge sharing throughout the entire problem-solving process within and between multiple fields, disciplines, and communities and exemplifies the importance of fostering sustainable networking pathways. Productive interactions between groups are fundamental to maximizing the capacity to collaboratively find a viable, just, and long-term solution to community problems. To understand effective knowledge sharing, we argue it is essential to study groups already doing this successfully. Uniminuto, a Colombian University, is a prime example of an academic institution that is striving to create a positive social impact on vulnerable communities. Through knowledge and experience gained in PCIS projects, they have created the "Social Innovation Route Framework" (Pacheco Duarte et al., 2021), a five-stage framework outlining community engagement projects, which is a powerful tool academic institutions, especially those related to engineering and design, can utilize to take a proactive role in (1) working with vulnerable groups to improve their labor and environmental conditions and (2) understanding the sociotechnical dimensions of their projects.

Our observations also reflect the benefits of educational proposals that combine knowledge of engineering with concepts from the sustainable community development framework, which is based on the social sciences. Thus, the interdisciplinary approaches that motivate students to make a contextual analysis of their projects—including history, politics, ideology, ethics, and culture—influence the way in which they develop their inventions. These approaches could also bring them closer to the Latin American context without falling into methodologies of North-South dominance.

To answer the many questions that were raised by this work, we foresee some additional areas for future research. First, there is a need for a deeper analysis of US and Latin American science engineering curriculum in order to understand the lack of urban mining content in curricula and identify synergistic opportunities with overseas academic entities. Second, further work needs to be done on screening current educational programs in the US, since our study is limited. Third, additional topics that should supplement the study of inclusive urban mining should be identified. Some topics that we believe could be beneficial to include are understanding the material politics of what is traditionally viewed as "waste" as well as learning social science approaches such as contextual and empathetic stakeholder engagement strategies to properly understand cities and their context.

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CHAPTER 5

THESIS CONCLUSIONS

The intention of this work, at a global level, is to motivate action towards occupational risk reduction interventions that focus not only on the protection of health and the environment of e-waste communities but also on the socioeconomic development of informal and semi-formal e-waste workers. At the national and local levels, this work aims to influence academic research, partnerships and policies for the development of environmentally sound and socially just interventions at the territorial level related to e-waste management.

The following sections present the main findings and limitations related to this research and commitments and recommendations for future work.

5.1 Main Findings

The first research question was intended to describe the chemical risks derived from the informal and semi-formal management of e-waste in two study sites as well as analyze the perceptions of workers and local authorities about the e-waste-related risks. In this sense, Chapter 2 illustrated two quite different risk scenarios. In both cases, the focus was on occupational and take-home risks, and additional considerations about combined exposure and syndemic exposure were included. At Site A, the e-waste workers were not grouped, and their activities were dispersed and relatively frequent. Open burning of e-waste, lead-acid batteries discharge, and manual dismantling of CRT TVs seemed to be the riskiest processes at this site. The available data suggested that chronic occupational and take-home exposures to hazardous substances (dioxins, furans, and lead as the most relevant) likely result from the open burning of copper cables. At Site B, the analysis focused on a cooperative transitioning into e-waste management located in an industrial complex. The riskiest processes identified were the manual dismantling of CRT TVs and the open burning of cables. However, those activities are not frequent and are performed once or twice a year. The riskiest practices at this site were mainly related to hygiene since an eating area was close to the working space and no hand washing areas were available nearby, nor were wet cleaning methods implemented. At this site, it was determined that chronic occupational exposures to hazardous chemicals due to the open burning of cables are unlikely. However, as a preventive approach, measures to control the risks of this activity were suggested. With regards to the perception of e-waste workers and officials from the local governmental agencies, the literature review indicated that, while the latter is generally objective, the perception of workers is usually low. In this study, it was not possible to characterize the risk perception of workers and officials as low/high. Nevertheless, some factors that affect their perceptions were described. These factors are: 1) tensions between inhabitants' and government officials' knowledge related to the socioenvironmental burdens associated with the area where workers live and work, 2) the view of milk as an "antidote," 3) the invisible and quiet chemical risks from chronic exposure versus the visible and disquieting subsistence priorities, 4) the protection of others (e.g., children, pregnant women) as a motivation to understand risks and act, 5) previous experiences with chemicals and the learning process, and 6) COVID-19 and best practices for preventing take-home exposure. The main contributions from the first research question were generating local data that are not generally available in academic spaces, e.g., characterization of the informal and semi-formal e-waste practices and the description of factors that affect perceptions and engaging in a broader academic conversation by promoting a focus-change towards occupational exposure in vulnerable contexts.

The second and third research questions aimed to generate concrete recommendations for reducing risks and stimulating local socioeconomic development, with a particular focus on Site A. Four levels of proposals in decreasing order of effectiveness —from the perspective of occupational safety— were discussed in Chapter 3: 1) Elimination of the open burning of copper cables through market interventions; 2) Substitution of the open burning of copper cables by the use of manual strippers or cable treatment machinery; 3) Controlled incineration of copper cables; 4) Implementation of administrative controls and use of PPE during the open burning of copper cables. The comprehensive evaluation of each proposal resulted from the qualitative data collected from the fieldwork and interviews. This evaluation determined that no solution fulfills every expectation (maximum revenues, productivity, safety, environmental protection) but provided significant data to inform the workers, officials, and researchers that will choose and implement the interventions. Improvements in cable classification processes, greater involvement of commercial intermediaries and metal recycling industries, and contextualized training and awareness raising are three common points of major relevance. The first main contribution of this research question was providing a framework to design interventions by extending the implementation of the NIOSH Hierarchy of Controls (US NIOSH, 2023) into informal contexts. A sociotechnical evaluation matrix was also developed based on the four criteria presented in Schlezak et al. (2022) and adapted from Bridger & Luloff (1999) and Lucena (2014). Another main contribution of this piece was calling attention to the most relevant factors that should be considered during the decision-making process, helping decision-makers narrow the scope of their efforts. These factors include 1) the potential of cooperatives and associations to become agents of change, 2) the need for an in-depth analysis of local resources so the interventions could be implemented with a long-term perspective, 3) the importance of increasing revenues and productivity, decreasing time and costs, but ensuring stable, secure, formal, economically sufficient, and decent jobs, and 4) the potential of peer-to-peer and door-to-door-based approaches to build trust with the community and contribute to the sustainability of the interventions.

Finally, Chapter 4 provided insights into future work in the field of urban mining (focusing on e-waste and construction and demolition waste), calling the attention of traditional mining and engineering professionals, scholars, and educators. It was found that urban mining has the potential to become the mining of the future. However, this field is not systematically included in educational programs in the US. From insights from previous artisanal small-scale gold mining (ASGM) experiences and practical examples of educational projects in first-, third-, and fourth-year courses at Colorado School of Mines, this work provided concrete recommendations for including urban mining in the curricula: 1) transdisciplinary projects between different programs, 2) proposals for design challenges, 3) undergraduate-graduate partnerships, and 4) the Co-creation ROUTE framework by Pacheco Duarte et al. (2021). In this study, it was also recognized that, in Latin America, urban mining activities provide job opportunities to vulnerable communities and offer additional benefits such as digital inclusion and empowerment of less-privileged groups. Participatory community-based research and qualitative and quantitative methods were suggested to understand and enhance these benefits.

5.2 Limitations of This Study and Some Other Considerations

First, it is noteworthy that, as Hausermann & Adomako (2022) describe, my positionality has inevitably impacted the research's design and implementation. First, how I defined the problem from the beginning was closely linked to the most common concerns in the field of government affairs, which is the field where I began my professional career as an engineer. In this way, the vision from the regulatory perspective, mainly focused on environmental and health protection, has been present from the beginning of the formulation of the problem and then reinforced by partnership with local government representatives. However, knowing that often the way in which regulators describe informal and semi-formal contexts tends to stigmatize informal workers, I also made an effort to include them during the planning of the thesis and its implementation. Likewise, complying with the ethical protocols, I ensured the protection of their identities in the different instances of research dissemination, including the publication of this thesis and other academic publications, as well as presentations at conferences and other events.

I also acknowledge that the privileges associated with my identity and those associated with being a Fulbright Scholar studying in the United States may have influenced access to and acceptance of my research by workers, as well as their perception of my interests and position of power. Noticing this situation, I took care while introducing myself. I was positioned as a student researcher, transparently stating the scope and limitations of my work and offering workers the opportunity to review the results of this research before being published. This way, I looked for a way to match their expectations with mine.

Additionally, I have performed a rapid ethnographic analysis, hence, it is noteworthy that the number of participants and the short time spent in the field may have led to overgeneralization, missing data and long-term trends, and unintended influence on the behavior of the participants. The latter is especially relevant in occupational health, where the external perspective on work tasks can have a considerable impact. Another important consideration about the participants is that in almost all the opportunities for interaction with the workers –except in one remote interview with a worker– the coordinators or people with a higher hierarchy were always present, which could have limited or influenced the data collected. The subjectivity in the selection of the participants was subject to their availability, to the decision of the key informants who acted as contact points, and to the limitations of time and resources of this research project.

5.3 Research Translation and Extension Commitments

After my graduation, I commit to continue implementing research translation and research extension by:

- Making the findings and recommendations of this thesis available and accessible to local regulators, workers, and their communities. I will produce short and clear dissemination material that could be presented in future workshops or webinars organized in partnership with the participants of the research project.
- Ensuring that local stakeholders have my contact details so they can reach out to me and clarify aspects of my work.
- Extending my research to other engineering and science students in Argentina and the US by participating in courses or lectures and contributing to the planning and developing of future research projects on urban mining.
- Publishing the data and findings in academic journals or conferences to contribute to global conversations and body of knowledge on e-waste.

5.4 Recommendations for Future Work

The increasing supply of EEE and the intention of local governments to increase the amounts of e-waste managed should only be promoted by taking into account the risks involved in the profession. That is why there must be clear directives for emerging sectors such as e-waste cooperatives, small businesses, university programs, and other initiatives. Specifically, to prevent the risks associated with the open burning of copper cables and general e-waste informal management practices, a series of suggestions for local authorities are presented below.

First, communication about workers' living and working conditions at both sites should be improved. The messages should be clear and respond to the main concerns of the inhabitants, including water quality and the sources of lead pollution. Other hazardous chemicals related to the management of e-waste should also be included in these messages. The communication strategy should target workers and local government officials interacting with them or making decisions that might affect them.

Second, although there are various vulnerable groups that must be protected, more attention should be paid to workers since they have the potential to prevent risks and are the most exposed population. Hence, opportunities for safer e-waste management practices should be analyzed and developed according to the opportunities and possibilities of the two study sites without impacting their socioeconomic status. It is also important to keep in mind that "the most important intervention is to identify and remove the source of exposure" (US ATSDR, 2020, p. 340).

Third, risk assessments should be extended to practices other than open burning of copper cables, including open burning of general e-waste and CRTs and batteries treatment. In doing so, existing data should be prioritized, and the use of human samples to generate data should be reduced as much as possible. Environmental samples to generate data are worth including. Furthermore, the information generated should always be effectively communicated to the population under study, ensuring transparency and providing spaces for reflection and mutual understanding.

Fourth, some areas that need further exploration are:

- Refinement of exposure data to perform a quantitative risk assessment, according to Chapter 2.
- Robust economic analysis of the interventions proposed in Chapter 3.
- Pilot implementation of the manual wire stripper proposed in Chapter 3.
- Analysis of the "Best-of-2-Worlds" philosophy (Chapter 3) in the contexts here described.
- Material and market analysis for plastics and printed circuit boards as two materials of high relevance for the participants interviewed.
- Study on how the Producer Extended Responsibility legal frameworks can include the informal sector.

Finally, I would like to conclude with the following quote by Gutberlet (2008a), which achieves to reflect the purpose of this MS thesis: "We need to consider how we can practice social justice with the most excluded and impoverished segment of society that is involved in recovering recyclables. (…) Can waste recovery be valued as a beneficial environmental service similar to other public services for the good of society?" (p.3).

REFERENCES

Acquah, A. A., D'Souza, C., Martin, B. J., Arko-Mensah, J., Botwe, P. K., Tettey, P., Dwomoh, D., Nti, A. A., Kwarteng, L., Takyi, S., Quakyi, I. A., Robins, T. G., & Fobil, J. N. (2021). A preliminary assessment of physical work exposures among electronic waste workers at Agbogbloshie, Accra Ghana. *International Journal of Industrial Ergonomics*, *82*, 103096. https://doi.org/10.1016/j.ergon.2021.103096

ACUMAR. (2018a). *Estrategia de Salud Ambiental. Documento de Consulta. Audiencia Pública.* IF-2018-53235166-APN-DSYEA#ACUMAR

ACUMAR. (2018b). *Site A dossier (Protected)*.

ACUMAR. (2019). *Site B dossier (Protected)*.

ACUMAR. (2021). *Plan Sanitario de Emergencia ACUMAR 2020-2023*. https://www.acumar.gob.ar/wp-content/uploads/2016/12/PSE-2020-2023-v2-prologo-1.pdf

Adach-Pawelus, K., Gogolewska, A., Górniak-Zimroz, J., Kiełczawa, B., Krupa-Kurzynowska, J., Paszkowska, G., Szyszka, D., Worsa-Kozak, M., & Woźniak, J. (2021). A New Face of Mining Engineer—International Curricula to Sustainable Development and Green Deal (A Case Study of the Wrocław University of Science and Technology). *Sustainability*, *13*(3), Article 3. https://doi.org/10.3390/su13031393

Akhtar, A., & Sarmah, A. K. (2018). Construction and demolition waste generation and properties of recycled aggregate concrete: A global perspective. *Journal of Cleaner Production*, *186*, 262–281. https://doi.org/10.1016/j.jclepro.2018.03.085

Aldebei, F., & Dombi, M. (2021). Mining the Built Environment: Telling the Story of Urban Mining. *Buildings*, *11*(9), Article 9. https://doi.org/10.3390/buildings11090388

Andrew, R. (2017). *Global Co2 Emissions from Cement Production* [Data set]. Zenodo. https://doi.org/10.5281/ZENODO.831455

Antolini, L. (2012). *Percepción del riesgo y dinámica de uso de plaguicidas agrícolas en el Valle Inferior del Río Chubut. Programa Nacional de Prevención y Control de las Intoxicaciones por Plaguicidas*.

Arain, A. L., & Neitzel, R. L. (2019). A Review of Biomarkers Used for Assessing Human Exposure to Metals from E-Waste. *International Journal of Environmental Research and Public Health*, *16*(10), 1802. https://doi.org/10.3390/ijerph16101802

Arain, A. L., Neitzel, R. L., Nambunmee, K., Hischier, R., Jindaphong, S., Austin-Breneman, J., & Jolliet, O. (2022). Material flow, economic and environmental life cycle performances of informal electronic waste recycling in a Thai community. *Resources, Conservation and Recycling*, *180*, 106129. https://doi.org/10.1016/j.resconrec.2021.106129

Asamoah, A., Nikbakht Fini, M., Essumang, D. K., Muff, J., & Søgaard, E. G. (2019). PAHs contamination levels in the breast milk of Ghanaian women from an e-waste recycling site and a residential area. *Science of The Total Environment*, *666*, 347–354. https://doi.org/10.1016/j.scitotenv.2019.02.204

Asante, K. A., Pwamang, J. A., Amoyaw-Osei, Y., & Ampofo, J. A. (2016). E-waste interventions in Ghana. *Reviews on Environmental Health*, *31*(1), 145–148. http://dx.doi.org/10.1515/reveh-2015-0047

Backyard Art (Director). (2020, February 24). *Los Mejores Pelacables: Evaluación de Distintos Tipos.* https://www.youtube.com/watch?v=Gb8kP2Vb_KY

Beebe, J. (2008). Basic Concepts and Techniques of Rapid Appraisal. *Human Organization*, *54*(1), 42–51. https://doi.org/10.17730/humo.54.1.k84tv883mr2756l3

Berardi, L. F. (2021). *Especialización en Higiene y Seguridad en el trabajo*. 42.

Blengini, G. A. (2009). Life cycle of buildings, demolition and recycling potential: A case study in Turin, Italy. *Building and Environment*, *44*(2), 319–330. https://doi.org/10.1016/j.buildenv.2008.03.007

Börner, S., Albino, J. C. T., Caraveo, L. M. N., & Tejeda, A. C. C. (2015). Exploring Mexican adolescents' perceptions of environmental health risks: A photographic approach to risk analysis. *Ciência & Saúde Coletiva*, *20*, 1617–1627. https://doi.org/10.1590/1413-81232015205.11382014

Bravo-German, A. M., Bravo-Gomez, I. D., Mesa, J. A., & Maury-Ramirez, A. (2021). *Mechanical Properties of Concrete Using Recycled Aggregates Obtained from Old Paving Stones*. https://doi.org/10.3390/su13063044

Bridger, J. C., & Luloff, A. E. (1999). Toward an interactional approach to sustainable community development. *Journal of Rural Studies*, *15*, 377–387.

Bungadaeng, S., Prueksasit, T., & Siriwong, W. (2019). Inhalation exposure to respirable particulate matter among workers in relation to their e-waste open burning activities in Buriram Province, Thailand. *Sustainable Environment Research*, *29*(1), 26. https://doi.org/10.1186/s42834-019-0030-7

Burastero, C. M. (2021). Residuos de aparatos eléctricos y electrónicos, ¿progreso o fracaso? *Ambiente en Diálogo*, *2*, Article 2.

Burastero, C. M. (2022). *La problemática de los RAEES: Consumo y descarte. Gestión de Residuos de Aparatos Eléctricos y Electrónicos en la Provincia de Buenos Aires.* [Tesina para la obtener el grado académico de Licenciatura en Gestión ambiental Urbana]. Universidad Nacional de Lanús.

Burns, K. N., Sayler, S. K., & Neitzel, R. L. (2019). Stress, health, noise exposures, and injuries among electronic waste recycling workers in Ghana. *Journal of Occupational Medicine and Toxicology (London, England)*, *14*, 1. https://doi.org/10.1186/s12995-018-0222-9

Burns, K. N., Sun, K., Fobil, J. N., & Neitzel, R. L. (2016). Heart Rate, Stress, and Occupational Noise Exposure among Electronic Waste Recycling Workers. *International Journal of Environmental Research and Public Health*, *13*(1), 140. https://doi.org/10.3390/ijerph13010140

Carenzo, S. (2017). Invisibilized creativity: Sociogenesis of an "innovation" process developed by cartoneros for post-consumption waste recycling. *International Journal of Engineering, Social Justice, and Peace*, 30–49. https://doi.org/10.24908/ijesjp.v5i1.8016

Carrillo, A. C. (2009). Internal displacement in Colombia: Humanitarian, economic and social consequences in urban settings and current challenges. *International Review of the Red Cross*, *91*(875), 527–546. https://doi.org/10.1017/S1816383109990427

Castillo, M., Tarando, M., Collado, J., Fatone, M., Mateu, M., Vona, P. J., Sarandón, F., & Carlo, B. (2022). *Guía para la Implementación de la Gestión Integral e Inclusiva de Residuos. Argentina Recicla*. Ministerio de Ambiente y Desarrollo Sostenible, Ministerio de Desarrollo Social. https://www.argentina.gob.ar/sites/default/files/2021/12/guia_para_la_implementacion_giirsu_24_feb_2022.pdf

Cazabat, C., & O'Connor, A. (2021). *2021 Internal Displacement Index Report* (p. 83). Internal Displacement Monitoring Centre. https://www.internal-displacement.org/sites/default/files/publications/documents/IDMC_Internal_Displacement_Index_Report_2021.pdf

Ceballos, D. M., & Dong, Z. (2016). The formal electronic recycling industry: Challenges and opportunities in occupational and environmental health research. *Environment International*, *95*, 157–166. https://doi.org/10.1016/j.envint.2016.07.010

Centro Regional Basilea para América del Sur & Ministerio de Ambiente y Desarrollo Sustentable de Argentina. (2018). *Actualización del Plan Nacional de Aplicación del Convenio de Estocolmo sobre contaminantes orgánicos persistentes, COPS, en la República Argentina*. Instituto Nacional de Tecnología Industrial (INTI). https://www.argentina.gob.ar/sites/default/files/5.3_plan_de_aplicacion_del_convenio_de_estocolmo_-_2017e_estocolmo_2017.pdf

Cesaro, A., Belgiorno, V., Gorrasi, G., Viscusi, G., Vaccari, M., Vinti, G., Jandric, A., Dias, M. I., Hursthouse, A., & Salhofer, S. (2019). A relative risk assessment of the open burning of WEEE. *Environmental Science and Pollution Research International*, *26*(11), 11042–11052. https://doi.org/10.1007/s11356-019-04282-3

Chand, S., Ranjan Rout, P., & Pathak, P. (2021). *Basic Concepts, Potentials, and Challenges of Urban Mining*. CRC Press.

Chi, X., Streicher-Porte, M., Wang, M. Y. L., & Reuter, M. A. (2011). Informal electronic waste recycling: A sector review with special focus on China. *Waste Management*, *31*(4), 731–742. https://doi.org/10.1016/j.wasman.2010.11.006

Chou, S., Arezoomand, M., Coulentianos, M. J., Nambunmee, K., Neitzel, R., Adhvaryu, A., & Austin-Breneman, J. (2021). The Stakeholder Agreement Metric: Quantifying Preference Agreement Between Product Stakeholders. *Journal of Mechanical Design*, *143*(3), 031710. https://doi.org/10.1115/1.4049315

Clinckspoor, G. L. (2018). *Residuos electrónicos: una revisión conceptual de un problema antrópico contemporáneo*. Nadir: Revista Electrónica de Geografía Austral, 10(1), 1- 13. http://revistanadir.yolasite.com/resources/ARTICULO%20CLINCKSPOOR%20%20Revista%20Nadir%202018.pdf

Clinckspoor, G. L., & Ferraro, R. F. (2020). Análisis de los actores involucrados en el tratamiento de los residuos electrónicos de las Tecnologías de la Información y Comunicación (TIC), en la ciudad de

Mar del Plata. *Antípoda. Revista de Antropología y Arqueología*, *39*, 41–64. https://doi.org/10.7440/antipoda39.2020.03

Clinckspoor, G., Martinez, A., & Ferraro, R. F. (2021). Revisión de los principales instrumentos normativos relacionados con residuos electrónicos, desde una perspectiva Norte y Sur Global. *Actualidad Jurídica Ambiental*, *109*(Sección "Comentarios").

Clinckspoor, G., & Suárez, F. M. (2018). Los RAEE, nuevos desafíos urbanos. Una aproximación a los estudios sobre residuos de aparatos electrónicos y eléctricos en Latinoamérica. In *Recicloscopio V* (1a. Ed.). Universidad Nacional de General Sarmiento.

Clinckspoor, G. L., & Zulaica, M. L. (2022). Análisis de las tecnologías empleadas en el posconsumo de residuos TIC en la ciudad de Mar del Plata. *Ciencia y Tecnología*, 73–88. https://doi.org/10.18682/cyt.vi22.8551

Colorado, H. A., Muñoz, A., & Neves Monteiro, S. (2022). *Circular Economy of Construction and Demolition Waste: A Case Study of Colombia*. Sustainability. https:// doi.org/10.3390/su14127225

Comesaña García, S. (2019). La economía circular y los residuos de aparatos eléctricos y electrónicos: Impactos sobre la salud infantil. *XV Congreso de Salud Ambiental*, *19 (Espec. Congr.),* 108–111.

Cossu, R., & Williams, I. D. (2015). Urban mining: Concepts, terminology, challenges. *Waste Management*, *45*, 1–3. https://doi.org/10.1016/j.wasman.2015.09.040

Coulentianos, M. J., Arezoomand, M., Chou, S., Austin-Breneman, J., Adhvaryu, A., Nambunmee, K., Neitzel, R., & Sienko, K. H. (2021). Product representations in conjoint analysis in an LMIC setting: Comparing attribute valuation when three-dimensional physical prototypes are shown versus two-dimensional renderings. *Development Engineering*, *6*, 100063. https://doi.org/10.1016/j.deveng.2021.100063

Daum, K., Stoler, J., & Grant, R. J. (2017). Toward a More Sustainable Trajectory for E-Waste Policy: A Review of a Decade of E-Waste Research in Accra, Ghana. *International Journal of Environmental Research and Public Health*, *14*(2), 135. https://doi.org/10.3390/ijerph14020135

Davey, B., & Walsh, E. (2019). Decent work in the management of electrical and electronic waste (e-waste). In International Labour Organization (Ed.), *Issues paper for the Global Dialogue Forum on Decent Work in the Management of Electrical and Electronic Waste (E-waste)*. International Labour Organization.

Davis, J.-M., & Garb, Y. (2015). A model for partnering with the informal e-waste industry: Rationale, principles and a case study. *Resources, Conservation and Recycling*, *105*, 73–83. https://doi.org/10.1016/j.resconrec.2015.08.001

Davor Mujezinovic. (2019, August 29). Electronic Waste in Guiyu: A City under Change? *Environment & Society Portal*. https://www.environmentandsociety.org/arcadia/electronic-waste-guiyu-city-under-change

Decharat, S., & Kiddee, P. (2022). Assessment of knowledge, attitude, perceptions and risk assessment among workers in e-waste recycling shops, Thailand. *Environmental Analysis Health and Toxicology*, *37*(1), e2022003.

DeJong, J. (2019). Desk Review of Artisanal and Small-Scale Gold Mining (ASGM) in Burkina Faso. *USAID Artisanal Mining and Property Rights Task Order under the Strengthening Tenure and Resource Rights II (STARR II) IDIQ, Washington, DC*.

Deng, J., Guo, J., Zhou, X., Zhou, P., Fu, X., Zhang, W., & Lin, K. (2014). Hazardous substances in indoor dust emitted from waste TV recycling facility. *Environmental Science and Pollution Research*, *21*(12), 7656–7667. https://doi.org/10.1007/s11356-014-2662-9

Dubois, F. I.; Sambeth, J. E.; Peluso, M. A. (2020). Reciclado de baterías de ion-Li agotadas. Aplicaciones tecnológicas de los metales recuperados. Capítulo de libros del Centro de Investigación en Ciencias Aplicadas "Dr. Jorge J. Ronco". 188-198. Universidad Nacional de La Plata. ISBN: 978-987-8348-83-4

Feiock, L. E. (2019). *Análisis descriptivo sobre las Evaluaciones Integrales de Salud Ambiental en Áreas de Riesgo (EISAAR) realizadas por la Dirección de Salud y Educación Ambiental de ACUMAR, en el territorio de la Cuenca Matanza Riachuelo. 2017-2019* (p. 40). ACUMAR.

Feng, H. (2021). *Making and Unmaking of Guiyu: The Global Center of E-waste* [Duke University. Master of Arts in the Graduate Liberal Studies Program.]. https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/23313/Harper's%20MP%20revised%201.pdf?sequence=1

Fernández Protomastro, G. (2013). *Minería urbana y la gestión de los residuos electrónicos*. Universidad ISALUD.

Fischhoff, B. (2009). Risk perception and communication. In *Risk Analysis and Human Behavior*.

Forti, V., Baldé, C. P., Kuehr, R., & Bel, G. (2021). *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential*. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA).

Francisco, J. T. M., Souza, A. E. de, & Teixeira, S. R. (2019). Construction and demolition waste in concrete: Property of pre-molded parts for paving. *Cerâmica*, *65*, 22–26. https://doi.org/10.1590/0366-6913201965S12595

Frazzoli, C., Orisakwe, O. E., Dragone, R., & Mantovani, A. (2010). Diagnostic health risk assessment of electronic waste on the general population in developing countries' scenarios. *Environmental Impact Assessment Review*, *30*(6), 388–399. https://doi.org/10.1016/j.eiar.2009.12.004

García Botero, L. M. (2003). Sostenibilidad de la disposición de escombros de construcción y demolición en Bogotá. *instname:Universidad de los Andes*. https://repositorio.uniandes.edu.co/handle/1992/10013

Ghisellini, P., Ncube, A., Casazza, M., & Passaro, R. (2022). Toward circular and socially just urban mining in global societies and cities: Present state and future perspectives. *Frontiers in Sustainable Cities*, *4*. https://www.frontiersin.org/articles/10.3389/frsc.2022.930061

Global Dialogue Forum on Decent Work in the Management of Electrical and Electronic Waste (e-waste) (GDFEEW). (2019). Points of consensus No. GDFEEW/2019/7. International Labout

Organization. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/meetingdocument/wcms_685681.pdf

Granados Santos, J. A., Perez Alvarez, N. B., & Poveda Zambrano, A. (2019). *Integral Solid Waste Management of the Department of Cundinamarca*.

Grant, K., Goldizen, F. C., Sly, P. D., Brune, M.-N., Neira, M., van den Berg, M., & Norman, R. E. (2013). Health consequences of exposure to e-waste: A systematic review. *The Lancet Global Health*, *1*(6), e350–e361. https://doi.org/10.1016/S2214-109X(13)70101-3

Grant, R. J., & Oteng-Ababio, M. (2016). The Global Transformation of Materials and the Emergence of Informal Urban Mining in Accra, Ghana. *Africa Today*, *62*(4), 3–20. https://doi.org/10.2979/africatoday.62.4.01

Greenpeace. (2011). *Basura informática. La otra cara de la tecnología*. https://wayback.archive-it.org/9650/20200516182039/http://p3-raw.greenpeace.org/argentina/Global/argentina/report/2011/contaminacion/basura_electronica_otra_cara_tecnologia.pdf

Grimes, S. M., & Maguire, D. (2020). Assessment of priorities in critical material recovery from Waste Electrical and Electronic Equipment. *Resources Policy*, *68*, 101658. https://doi.org/10.1016/j.resourpol.2020.101658

Gutberlet, J. (2008a). *Recovering Resources—Recycling Citizenship* (0 ed.). Routledge. https://doi.org/10.4324/9781315604084

Gutberlet, J. (2008b). Empowering collective recycling initiatives: Video documentation and action research with a recycling co-op in Brazil. *Resources, Conservation and Recycling*, *52*(4), 659–670. https://doi.org/10.1016/j.resconrec.2007.08.006

Gutberlet, J. (2008c). Empowering collective recycling initiatives: Video documentation and action research with a recycling co-op in Brazil. *Resources, Conservation and Recycling*, *52*(4), 659–670. https://doi.org/10.1016/j.resconrec.2007.08.006

Gutberlet, J. (2009). Solidarity economy and recycling co-ops in São Paulo: Micro-credit to alleviate poverty. *Development in Practice*, *19*(6), 737–751. https://doi.org/10.1080/09614520903026892

Gutberlet, J., Baeder, A. M., Pontuschka, N. N., Felipone, S. M. N., & Dos Santos, T. L. F. (2013). Participatory Research Revealing the Work and Occupational Health Hazards of Cooperative Recyclers in Brazil. *International Journal of Environmental Research and Public Health*, *10*(10), Article 10. https://doi.org/10.3390/ijerph10104607

Gutberlet, J., & Carenzo, S. (2020). Waste Pickers at the Heart of the Circular Economy: A Perspective of Inclusive Recycling from the Global South. *Worldwide Waste: Journal of Interdisciplinary Studies*, *3*(1), Article 1. https://doi.org/10.5334/wwwj.50

Harguindeguy, A. I. (2022). *Evaluación económico-financiera para la instalación de una planta de separación de residuos de aparatos eléctricos y electrónicos en la ciudad de Bahía Blanca*.

Hausermann, H., & Adomako, J. (2022). Positionality, ‘the field,’ and implications for knowledge production and research ethics in land change science. *Journal of Land Use Science*, *17*(1), 211–225. https://doi.org/10.1080/1747423X.2021.2015000

Heacock, M., Kelly, C. B., Asante, K. A., Birnbaum, L. S., Bergman, Å. L., Bruné, M.-N., Buka, I., Carpenter, D. O., Chen, A., Huo, X., Kamel, M., Landrigan, P. J., Magalini, F., Diaz-Barriga, F., Neira, M., Omar, M., Pascale, A., Ruchirawat, M., Sly, L., … Suk, W. A. (2016). E-Waste and Harm to Vulnerable Populations: A Growing Global Problem. *Environmental Health Perspectives*, *124*(5), 550–555. https://doi.org/10.1289/ehp.1509699

Heacock, M., Trottier, B., Adhikary, S., Asante, K. A., Basu, N., Brune, M.-N., Caravanos, J., Carpenter, D., Cazabon, D., Chakraborty, P., Chen, A., Barriga, F. D., Ericson, B., Fobil, J., Haryanto, B., Huo, X., Joshi, T. K., Landrigan, P., Lopez, A., … Suk, W. (2018). Prevention-intervention strategies to reduce exposure to e-waste. *Reviews on Environmental Health*, *33*(2), 219–228. https://doi.org/10.1515/reveh-2018-0014

Huisman, J., Stevels, A., Baldé, K., Magalini, F., & Kuehr, R. (2019). Chapter 3—The e-waste development cycle, part II—impact assessment of collection and treatment. In V. Goodship, A. Stevels, & J. Huisman (Eds.), *Waste Electrical and Electronic Equipment (WEEE) Handbook (Second Edition)* (pp. 57–92). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-102158-3.00003-3

International Labour Organization (ILO). (1999). *Report of the Director-General: Decent work. ILC87*. https://www.ilo.org/public/english/standards/relm/ilc/ilc87/rep-i.htm

International Labour Organization (ILO). (2002). *Recommendation R193—Promotion of Cooperatives*. Retrieved February 24, 2023, from https://www.ilo.org/dyn/normlex/en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:R193

International Labour Organization (ILO). (2016). *What is a green job ?* Retrieved in December 15, 2022 from: http://www.ilo.org/global/topics/green-jobs/news/WCMS_220248/lang--en/index.htm

International Labour Organization, (ILO). (2019). *Estimación del empleo verde en Argentina*. https://www.ilo.org/wcmsp5/groups/public/---americas/---ro-lima/---ilo-buenos_aires/documents/publication/wcms_750434.pdf

International Labour Organization (ILO). (2023). *Advancing decent work in e-waste management and the overall circular economy. Brief on electronic waste management and circular economy (Background document for information).* (Sectoral Advisory Bodies). International Labour Organization. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/meetingdocument/wcms_865293.pdf

International Telecommunication Union (ITU). (2023). *Connect 2030 – An agenda to connect all to a better world*. ITU. Retrieved March 1, 2023, from https://www.itu.int:443/en/mediacentre/backgrounders/Pages/connect-2030-agenda.aspx

Jacobs, J. (1969). *The Economy of Cities*. Random House, New York. https://jacobs.owlstown.net/publications/2

Jasanoff, S. (1993). Bridging the Two Cultures of Risk Analysis. In *Risk Analysis* (Vol. 13, pp. 123–129).

Jensen, M., Combariza Bayona, D. A., & Sripada, K. (2021). Mercury Exposure among E-Waste Recycling Workers in Colombia: Perceptions of Safety, Risk, and Access to Health Information. *International Journal of Environmental Research and Public Health*, *18*(17), Article 17. https://doi.org/10.3390/ijerph18179295

Johansson, N., Krook, J., Eklund, M., & Berglund, B. (2013). An integrated review of concepts and initiatives for mining the technosphere: Towards a new taxonomy. *Journal of Cleaner Production*, *55*, 35–44. https://doi.org/10.1016/j.jclepro.2012.04.007

Kabirifar, K., Mojtahedi, M., Wang, C., & Tam, V. W. Y. (2020). Construction and demolition waste management contributing factors coupled with reduce, reuse, and recycle strategies for effective waste management: A review. *Journal of Cleaner Production*, *263*, 121265. https://doi.org/10.1016/j.jclepro.2020.121265

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Koutamanis, A., van Reijn, B., & van Bueren, E. (2018). Urban mining and buildings: A review of possibilities and limitations. *Resources, Conservation and Recycling*, *138*, 32–39. https://doi.org/10.1016/j.resconrec.2018.06.024

Kwarteng, L., Baiden, E. A., Fobil, J., Arko-Mensah, J., Robins, T., & Batterman, S. (2020). Air Quality Impacts at an E-Waste Site in Ghana Using Flexible, Moderate-Cost and Quality-Assured Measurements. *GeoHealth*, *4*(8), e2020GH000247. https://doi.org/10.1029/2020GH000247

Kwarteng, L., Devasurendra, A. M., Laskaris, Z., Arko-Mensah, J., Amoabeng Nti, A. A., Takyi, S., Acquah, A. A., Dwomoh, D., Basu, N., Robins, T., Fobil, J. N., & Batterman, S. (2022). Occupational exposures to particulate matter and PM2.5-associated polycyclic aromatic hydrocarbons at the Agbogbloshie waste recycling site in Ghana. *Environment International*, *158*, 106971. https://doi.org/10.1016/j.envint.2021.106971

Laskaris, Z., Milando, C., Batterman, S., Mukherjee, B., Basu, N., O'neill, M. S., Robins, T. G., & Fobil, J. N. (2019). Derivation of Time-Activity Data Using Wearable Cameras and Measures of Personal Inhalation Exposure among Workers at an Informal Electronic-Waste Recovery Site in Ghana. *Annals of Work Exposures and Health*, *63*(8), 829–841. https://doi.org/10.1093/annweh/wxz056

Lepawsky, J., Araujo, E., Davis, J.-M., & Kahhat, R. (2017). Best of two worlds? Towards ethical electronics repair, reuse, repurposing and recycling. *Geoforum*, *81*, 87–99. https://doi.org/10.1016/j.geoforum.2017.02.007

Li, L., Liu, G., Pan, D., Wang, W., Wu, Y., & Zuo, T. (2017). Overview of the recycling technology for copper-containing cables. *Resources, Conservation and Recycling*, *126*, 132–140. https://doi.org/10.1016/j.resconrec.2017.07.024

Li, W., & Achal, V. (2020). Environmental and health impacts due to e-waste disposal in China – A review. *Science of The Total Environment*, *737*, 139745. https://doi.org/10.1016/j.scitotenv.2020.139745

Lopes dos Santos, K. (2022). Unequal geographies of urban mining: E-waste management in London, Sao Paulo and Accra. *Environment and Planning E: Nature and Space*, 25148486221128150. https://doi.org/10.1177/25148486221128154

Lora Reyes, N. J. (2017). *Análisis de la Exposición a Plomo en los Trabajadores que Desensamblan Residuos de Aparatos Eléctricos y Electrónicos (RAEE) en la Empresa Orinoco E-Scrap S.A.S.* [Universidad Distrital Francisco José de Caldas]. https://repository.udistrital.edu.co/bitstream/handle/11349/7313/LoraReyesNataliJoanna2017.pdf?sequence=1&isAllowed=y

Lucena, J. (2014). Towards an ethics of international service learning: How history, engineering cultures and views of communities should matter to engineers' serving abroad. In M. Lima & W. C. Oakes (Eds.), *Service-learning: Engineering in your community* (Second edition, p. Chapter 12). Oxford University Press.

Lucena, J. (2020). Can Community Development Projects in Engineering Education Be Both Responsible and Sustainable?: Theory, Education, and Praxis. *2020 ASEE Virtual Annual Conference Content Access Proceedings*, 34254. https://doi.org/10.18260/1-2--34254

Lucena, J., Chapman, E., Rojas, M., Schlezak, S., & Styer, J. (2022). *Bringing it down from the ivory tower: Translating Engineering-for-Community-Development (ECD) graduate student research into community engagement and undergraduate student learning*. ASEE 2022 Annual Conference.

Lucena, J., Schneider, J., & Leydens, J. A. (2010). *Engineering and Sustainable Community Development* (C. Baillie, Ed.). Morgan & Claypool.

Lundgren, K., International Labour Office, Programme on Safety and Health at Work and the Environment, International Labour Office, & Sectoral Activities Department. (2012). *The global impact of e-waste: Addressing the challenge*. ILO.

Luo, T., Hang, J. G., Nakayama, S. F., Jung, C.-R., Ma, C. C., Kido, T., Wang, F. H., Wang, Z., Dong, J. J., Shi, L. L., & Sun, X. L. (2021). Dioxins in breast milk of Chinese mothers: A survey 40 years after the e-waste recycling activities. *Science of The Total Environment*, *758*, 143627. https://doi.org/10.1016/j.scitotenv.2020.143627

Maffei, L., & Burucua, A. (2020). *Residuos de Aparatos Eléctricos y Electrónicos (RAEE) y empleo en la Argentina*. Organización Internacional del Trabajo (OIT). https://www.ilo.org/wcmsp5/groups/public/---americas/---ro-lima/---ilo-buenos_aires/documents/publication/wcms_737650.pdf

Maffei, L., Di Santo, C., Martínez, L., Rodríguez, E., Burucua, A., Iribarne, R., & Malalán, T. (2020). *Gestión Integral de RAEE. Los residuos de aparatos eléctricos y electrónicos, una fuente de trabajo decente para avanzar hacia la economía circular.* Ministerio de Ambiente y Desarrollo Sostenible de la Nación, Oficina de País de la Organización Internacional del Trabajo para Argentina.

Magalini, F., Kuehr, R., & Baldé, C. P. (2015). *eWaste en América Latina. Análisis estadístico y recomendaciones de política pública*. UNU-IAS SCYCLE, GSMA. https://www.gsma.com/latinamerica/wp-content/uploads/2015/11/gsma-unu-ewaste2015-spa.pdf

Marcoccia, C. G., Peluso, M. A., & Sambeth, J. E. (2020). Synthesis, characterization and catalytic properties of cobalt oxide recovered from spent lithium-ion batteries. *Molecular Catalysis*, 481, 110223. https://doi.org/10.1016/j.mcat.2018.10.018

Margallo, M., Ziegler-Rodriguez, K., Vázquez-Rowe, I., Aldaco, R., Irabien, Á., & Kahhat, R. (2019). Enhancing waste management strategies in Latin America under a holistic environmental assessment perspective: A review for policy support. *Science of The Total Environment, 689*, 1255–1275. https://doi.org/10.1016/j.scitotenv.2019.06.393

McDonald, L., Gorodetsky, D., Fernandez, L., & Rotshuizen. (2017). *Inclusive Recycling. Five Building Blocks for Implementing Sustainable Systems in Low & Middle Income Countries.* MIT Practical Impact Alliance.

Meissner, H., Creswell, J., Klassen, A. C., Plano, V., & Smith, K. C. (2011). *Best Practices for Mixed Methods Research in the Health Sciences*.

Mendez-Fajardo, S. (2011). *APROVECHAMIENTO DE ESCOMBROS: UNA OPORTUNIDAD PARA MEJORAR LA INFRAESTRUCTURA DE LAS COMUNIDADES MARGINADAS*.

Mining Schools and Universities. *National Mining Association*. Retrieved March 1, 2023, from https://nma.org/about-nma-2/resources/mining-schools-and-universities/

Ministry of Labor, Employment, and Social Security in Argentina. (2022). Resolución No. 11/2022. https://www.boletinoficial.gob.ar/detalleAviso/primera/270290

Ministry of Environment and Sustainable Development of Colombia. (2017). *Resolución 472 de 2017.* https://www.redjurista.com/Documents/resolucion_no._472_de_2017.aspx

Ministry of Environment and Sustainable Development of Colombia. (2021). *Resolution 1257 of 2021*.

Ministry of Environment of Colombia. (1994). *Resolution 541 of December 14, 1994*.

Ministry of Social Development in Argentina. (2022). *Banco de Máquinas y Herramientas*. Retrieved, 1 December, 2022 from https://www.argentina.gob.ar/desarrollosocial/emprendedoresycooperativassociales/banco-de-maquinas-y-herramientas

Muntaka Chasant. (2019). A glimmer of hope comes to Agbogbloshie. *GhanaWeb*. Retrieved in March 29 2022 from https://www.ghanaweb.com/GhanaHomePage/features/A-glimmer-of-hope-comes-to-Agbogbloshie-734022

Murty, P. S. R. (2017). Chapter 7—Cables. In P. S. R. Murty (Ed.), *Electrical Power Systems* (pp. 145–169). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-08-101124-9.00007-3

Nakamura, T., & Halada, K. (2015). Potential of Urban Mine. In T. Nakamura & K. Halada (Eds.), *Urban Mining Systems* (pp. 7–29). Springer Japan. https://doi.org/10.1007/978-4-431-55075-4_2

National Executive Power in Argentina. (1993). Decree No. 831/93 that regulates Law No. N° 24.051 on Hazardous Waste. https://www.argentina.gob.ar/

National Executive and Legislative Powers in Argentina. (1995). *Law N° 24.557 on Occupational Risks*, (testimony of National Executive Power of Argentina). https://www.argentina.gob.ar/

National Executive Power in Argentina. (2022). Decree No. 651/2022. https://www.argentina.gob.ar/sites/default/files/2022/09/decreto_6512022.pdf

Neitzel, R. L., Sayler, S. K., Arain, A. L., & Nambunmee, K. (2020). Metal Levels, Genetic Instability, and Renal Markers in Electronic Waste Workers in Thailand. *The International Journal of Occupational and Environmental Medicine*, *11*(2), 72–84. https://doi.org/10.34172/ijoem.2020.1826

Newman, N., Jones, C., Page, E., Ceballos, D., & Oza, A. (2015). Investigation of Childhood Lead Poisoning from Parental Take-Home Exposure from an Electronic Scrap Recycling Facility—Ohio, 2012. *Morbidity and Mortality Weekly Report*, *64*(27), 743–745.

Nieusma, D., & Riley, D. (2010). Designs on development: Engineering, globalization, and social justice. *Engineering Studies*, *2*(1), 29–59. https://doi.org/10.1080/19378621003604748

Nieuwenhuijsen, M. J. (2005). Design of exposure questionnaires for epidemiological studies. *Occupational and Environmental Medicine*, *62*(4), 272–280. https://doi.org/10.1136/oem.2004.015206

Ntapanta, S. M. (2021). ‘Lifescaping’ toxicants: Locating and living with e-waste in Tanzania. *Anthropology Today*, *37*(4), 7–10. https://doi.org/10.1111/1467-8322.12663

Occupational Safety and Health Administration (OSHA). *Occupational Safety and Health Standard 1910.1025—Lead*, (2020). https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1025

Ojeda, J., & Donnelly, L. (2006). *Landslides in Colombia and their impact on towns and cities*. The Geological Society of London.

Organismo Provincial de Integración Social y Urbana (OPISU) in Buenos Aires. (2021). *IMPACT.Ar Challenge: E-waste in disadvantaged communities. Project application*. https://www.argentina.gob.ar/sites/default/files/19_if-2021-15742172-apn-ddygdmct.pdf

Organismo Provincial para el Desarrollo Sostenible (OPDS) in Buenos Aires (2019). Resolución 269/19, no. 269/19. https://www.ambiente.gba.gob.ar/sites/default/files/Resoluci%C3%B3n%20269%2019.pdf

Ottinger, G. (2011). Rupturing engineering education: Opportunities for transforming expert identities through community-based projects. In *Technoscience and Environmental Justice: Expert Cultures in a Grassroots Movement*. The MIT Press.

Platform for Accelerating the Circular Economy (PACE). (2021). *Circular Economy Action Agenda: Electronics*. https://pacecircular.org/sites/default/files/2021-02/action-agenda-electronics-feb2021_FINAL.pdf

Pacheco Bustos, C. A., Fuentes Pumarejo, L. G., Sánchez Cotte, É. H., Rondón Quintana, H. A. (2017). Residuos de construcción y demolición (RCD), una perspectiva de aprovechamiento para la ciudad de barranquilla desde su modelo de gestión. *Ingeniería y Desarrollo*, *35*(2), 533–555.

Pacheco Duarte, J. F., Rodríguez Pupo, E. S., & Galindo Gómez, S. F. (2021). *“Social innovation route: Step by step to develop social innovations.” ["Ruta de innovación social: Paso a paso para desarrollar innovaciones sociales."]*. https://repository.uniminuto.edu/handle/10656/11502

Paiva, V., & Banfi, J. (2016). Cartoneros, espacio público y estrategias de supervivencia. Mar del Plata, Argentina, 1990-2014. *Sociologias*, *18*(41), 270–290. https://doi.org/10.1590/15174522-018004113

Pan American Health Organization, (PAHO). (2023). *Curso “Los niños, las niñas y los basureros digitales: Exposición a los residuos electrónicos y la salud infantil (RAEE).”* https://www.campusvirtualsp.org/es/curso/los-ninos-y-los-basureros-digitales-exposicion-los-residuos-electronicos-y-salud-infantil

Pinch, T. J., & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. *Social Studies of Science*, *14*(3), 399–441.

Prakash, S., Manhart, A., & Box, P. O. (2010). *Socio-economic assessment and feasibility study on sustainable e-waste management in Ghana*. 118.

Protomastro, G. F. (2007). *Estudio sobre los circuitos formales e informales de gestión de Residuos de Aparatos Eléctricos y Electrónicos en Argentina*. https://www.residuoselectronicos.net/archivos/lineas_base/LINEA_BASE_ARGENTINA_FERNANDEZPROTOMASTRO.pdf

Protomastro, G. F. (2014). *Buenas prácticas para la gestión sostenible de los residuos de aparatos eléctricos y electrónicos RAEE* (1a. Ed.). Edit. Grupo Uno. Proyecto de la Unión Europea y MERCOSUR.

Pure Earth. (2015). *Project Completion Report: Making Electronic Waste Recycling in Ghana Safer Through Alternative Technology, Accra Ghana*. http://www.pureearth.org/wp-content/uploads/2021/03/Ghana-Pilot-PCR-2015.pdf

Qin, Q., Xu, X., Dai, Q., Ye, K., Wang, C., & Huo, X. (2019). Air pollution and body burden of persistent organic pollutants at an electronic waste recycling area of China. *Environmental Geochemistry and Health*, *41*(1), 93–123. https://doi.org/10.1007/s10653-018-0176-y

Rodríguez, E. (2019). *Gestión Integral de Residuos Informáticos*. *16*, 5.

Rousis, K., Moustakas, K., Malamis, S., Papadopoulos, A., & Loizidou, M. (2008). Multi-criteria analysis for the determination of the best WEEE management scenario in Cyprus. *Waste Management*, *28*(10), 1941–1954. https://doi.org/10.1016/j.wasman.2007.12.001

Salcedo, G. A., Felicetti, R., & Pelloli, C. G. (2019). *Cooperación y reciclado para un mundo sustentable*. CETCOT- Centro de Transferencia de Conocimiento y Tecnología. Universidad de Buenos Aires. https://ambienteysociedad.org/wp-content/uploads/2021/09/Manual-final-editado-den.pdf

Schaap, I., & Slijkerman, D. M. E. (2018). An environmental risk assessment of three organic UV-filters at Lac Bay, Bonaire, Southern Caribbean. *Marine Pollution Bulletin*, *135*, 490–495. https://doi.org/10.1016/j.marpolbul.2018.07.054

Schamber, P. J. (2006). *De los desechos a las mercancías. Antropología del reciclaje de residuos en el conurbano bonaerense* [PhD Thesis]. Facultad de Filosofía y Letras, Universidad de Buenos Aires.

Schettini, P., & Herrero, V. (2017). Cartoneros y recuperadores urbanos de residuos como trabajadores informales organizados: Algunas reflexiones a partir de un estudio en la Ciudad de La Plata. *Seminario Internacional Desigualdad y Movilidad Social en América Latina*, 22. http://www.memoria.fahce.unlp.edu.ar/trab_eventos/ev.10625/ev.10625.pdf

Schlezak, S., Lucena, J., Handorean, A., Antolini, L., Neitzel, R., & Baena, O. R. (2022). A sociotechnical analysis of interventions to promote safer working conditions in informal e-waste recycling settings. *2022 IEEE Global Humanitarian Technology Conference (GHTC)*, 387–390. https://doi.org/10.1109/GHTC55712.2022.9910976

Schluep, M., Spitzbart, M., & Blaser, F. (2015). *Dismantling Guide for IT - Equipment* (Sustainable Recycling Industries, Institute for Materials Science & Technology Empa, World Resources Forum WRF, Dismantling- and Recycling-Centre DRZ, & UNIDO, Eds.).

Seith, R., Arain, A., Nambunmee, K., Adar, S., & Neitzel, R. (2019). Self-Reported Health and Metal Body Burden in an Electronic Waste Recycling Community in Northeastern Thailand. *Journal of Occupational and Environmental Medicine*, *61*, 1. https://doi.org/10.1097/JOM.0000000000001697

Sepúlveda, R., Schluep, M., Renaud, F. G., Streicher, M., & Kuehr, R. (2010). A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India. *Environmental Impact Assessment Review*, *30*, 28–41. https://doi.org/10.1016/j.eiar.2009.04.001

Shkembi, A., Nambunmee, K., Jindaphong, S., Parra Giordano, D., Yohannessen, K., Ruiz-Rudolph, P., Neitzel, R., & Arain, A. (2021). Work Task Association with Lead Urine and Blood Concentrations in Informal Electronic Waste Recyclers in Thailand and Chile. *International Journal of Environmental Research and Public Health*, *18*, 10580. https://doi.org/10.3390/ijerph182010580

Singhal, D., Lyngdoh, T., & Prabhakaran, P. (2021). Knowledge, Attitude and Practice Study of Health Risks Among E-waste Recyclers in Delhi. *Journal of Health and Pollution*, *11*(29), 210306. https://doi.org/10.5696/2156-9614-11.29.210306

Smith, J., Lucena, J., Rivera, A., Phelan, T., Smits, K., & Bullock, R. (2021). Developing Global Sociotechnical Competency Through Humanitarian Engineering: A Comparison of In-Person and Virtual International Project Experiences. *Journal of International Engineering Education*, *3*(1). https://digitalcommons.uri.edu/jiee/vol3/iss1/5

Song, Q., & Li, J. (2014). A systematic review of the human body burden of e-waste exposure in China. *Environment International*, *68*, 82–93. https://doi.org/10.1016/j.envint.2014.03.018

Spradley, J. P. (2016). *The ethnographic interview*. Waveland Press, Inc.

Srigboh, R. K., Basu, N., Stephens, J., Asampong, E., Perkins, M., Neitzel, R. L., & Fobil, J. (2016). Multiple Elemental Exposures Amongst Workers at the Agbogbloshie Electronic Waste (E-

Waste) Site in Ghana. *Chemosphere, 164*, 68–74. https://doi.org/10.1016/j.chemosphere.2016.08.089

Standaert, M. (2015). China's Notorious E-waste Village Disappears Almost Overnight. *International Environment Reporter. Basel Action Network*. https://www.ban.org/news/2015/12/17/chinas-notorious-e-waste-village-disappears-almost-overnight

Step Initiative. (2014). *One Global Definition of E-Waste*. United Nations University. https://collections.unu.edu/eserv/UNU:6120/step_one_global_definition_amended.pdf

Stockholm Convention. (2004). *Draft Guidelines on Best Available Techniques (BAT) for Smouldering of Copper Cables*. http://chm.pops.int/Portals/0/docs/from_old_website/documents/meetings/bat_bep/2nd_session/egb2_followup/draftguide/6LCopperCablesDRAFT.pdf

Suárez-Silgado, S. S., Betancourt-Quiroga, C., Molina-Benavides, J., Mahecha-Vanegas, L. (2019). "Construction and demolition waste management in Villavicencio: Current status, barriers and management instruments" ["La gestión de los residuos de construcción y demolición en Villavicencio: Estado actual, barreras e instrumentos de gestión"]. *Entramado, 15*(1), 224–244. https://doi.org/10.18041/1900-3803/entramado.1.5408

Superintendencia de Riesgos del Trabajo (SRT). (2018). *Guía de actuación y diagnóstico de enfermedades profesionales: 01. Exposición al plomo.*

Thomas, H., Fressoli, M., Becerra, L., Garrido, S., & Juarez, P. (2017). Theoretical and policy failures in technologies and innovation for social inclusion: The cases of social housing, renewal energy and food production in Argentina. In S. Kuhlmann & G. Ordóñez-Matamoros, *Research Handbook on Innovation Governance for Emerging Economies* (pp. 493–520). Edward Elgar Publishing. https://doi.org/10.4337/9781783471911.00025

Thormark, C. (2006). The effect of material choice on the total energy need and recycling potential of a building. *Building and Environment, 41*(8), 1019–1026. https://doi.org/10.1016/j.buildenv.2005.04.026

Tsydenova, O., & Bengtsson, M. (2011). Chemical hazards associated with treatment of waste electrical and electronic equipment. *Waste Management, 31*(1), 45–58. https://doi.org/10.1016/j.wasman.2010.08.014

Turner, A., & Filella, M. (2021). Lead in plastics – Recycling of legacy material and appropriateness of current regulations. *Journal of Hazardous Materials, 404*, 124131. https://doi.org/10.1016/j.jhazmat.2020.124131

United Nations Institute for Training and Research (UNITAR) & United Nations Environment Programme (UNEP). (2018). *Handbook for Developing National ASGM Formalization Strategies within National Action Plans*. UNITAR & UN Environment. https://www.internal-displacement.org/sites/default/files/2021-05/figure-analysis-col_0.pdf

United Nations Environment Programme (UNEP). (2015). *Global Waste Management Outlook*.

United Nations Environment Programme (UNEP). (2020). *Building sector emissions hit record high, but low-carbon pandemic recovery can help transform sector – UN report*. UN Environment.

http://www.unep.org/news-and-stories/press-release/building-sector-emissions-hit-record-high-low-carbon-pandemic

Universidad El Bosque. (2021). *Regional electronics study and circularity in the America and the Caribbean (LAC) region. Mapping of stakeholders.* https://saicmknowledge.org/sites/default/files/publications/LAC%20electronics%20study_Mapping%20of%20stakeholders.pdf

US Agency for Toxic Substances and Disease Registry. (2020). *Toxicological Profile for Lead*. https://www.atsdr.cdc.gov/toxprofiles/tp13.pdf

US National Institute of Environmental Health Sciences. (2017). Global Environmental Health. *E-Waste: Prevention Intervention Strategies Meeting Summary*. Side Event to the 17th International Conference of the Pacific Basin Consortium. https://www.niehs.nih.gov/research/assets/docs/2017_prevention_intervention_strategies_ewaste_meeting_report_508.pdf

US Environmental Protection Agency (EPA). (2014). Framework for Human Health Risk Assessment to Inform Decision Making. *Office of the Science Advisor. Risk Assessment Forum*.

US National Research Council. (1983). *Risk Assessment in the Federal Government: Managing the Process.Managing the process.* (p. 366). National Academies Press. https://doi.org/10.17226/366

US National Institute for Occupational Safety & Health (NIOSH). (2019). Ramsey , J., Grimes, G., & Beaucham, C. *Evaluation of exposures to metals and flame retardants at an electronics recycling company.* U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention. https://doi.org/10.26616/NIOSHHHE201700133356

US National Institute for Occupational Safety & Health (NIOSH). (2023). *Hierarchy of Controls*. https://www.cdc.gov/niosh/topics/hierarchy/default.html

Vergara, S. E., Damgaard, A., & Gomez, D. (2016). The Efficiency of Informality: Quantifying Greenhouse Gas Reductions from Informal Recycling in Bogotá, Colombia: Quantifying GHG Reductions from Informal Recycling in Colombia. *Journal of Industrial Ecology*, *20*(1), 107–119. https://doi.org/10.1111/jiec.12257

Wagner, M., Baldé, C. P., Luda, V., Nnorom, I. C., Kuehr, C., & Iattoni, G. (2022). *Regional E-waste Monitor for Latin America: Results for the 13 countries participating in project UNIDO-GEF 5554*. https://api.globalewaste.org/publications/file/284/Regional-E-waste-Monitor-for-Latin-America-2022.pdf

Wang, F., Huisman, J., Meskers, C. E. M., Schluep, M., Stevels, A., & Hagelüken, C. (2012). The Best-of-2-Worlds philosophy: Developing local dismantling and global infrastructure network for sustainable e-waste treatment in emerging economies. *Waste Management*, *32*(11), 2134–2146. https://doi.org/10.1016/j.wasman.2012.03.029

Wang, Y., Hu, J., Lin, W., Wang, N., Li, C., Luo, P., Hashmi, M. Z., Wang, W., Su, X., Chen, C., Liu, Y., Huang, R., & Shen, C. (2016). Health risk assessment of migrant workers’ exposure to polychlorinated biphenyls in air and dust in an e-waste recycling area in China: Indication for a new wealth gap in environmental rights. *Environment International*, *87*, 33–41. https://doi.org/10.1016/j.envint.2015.11.009

Warren, C. A. B., & Karner, T. X. (2015). *Discovering qualitative methods: Ethnography, interviews, documents, and images* (Third edition). Oxford University Press.

World Health Organization (WHO) & Food and Agriculture Organization (FAO). (2011). *Evaluations of the Joint FAO/WHO Expert Committee on Food Additives (JECFA): Lead*. https://apps.who.int/food-additives-contaminants-jecfa-database/Home/Chemical/3511

World Bank. (2023). *Gini index—Argentina. World Bank, Poverty and Inequality Platform.* Retrieved in March 15, 2023 from: https://data.worldbank.org/indicator/SI.POV.GINI?locations=AR

World Health Organization. (2021a). *Children and digital dumpsites: E-waste exposure and child health*. World Health Organization. https://apps.who.int/iris/handle/10665/341718

World Health Organization. (2021b). *WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.* https://apps.who.int/iris/bitstream/handle/10665/345329/9789240034228-eng.pdf?sequence=1&isAllowed=y

World Health Organization, (WHO). (2021c). *Framework for the use of systematic review in chemical risk assessment*. https://doi.org/Licence: CC BY-NC-SA 3.0 IGO.

World Health Organization, (WHO). (2023). *Types of pollutants*. Retrieved in March 15, 2023 from https://www.who.int/teams/environment-climate-change-and-health/air-quality-and-health/health-impacts/types-of-pollutants

Xavier, L. H., Ottoni, M., & Abreu, L. P. P. (2023). A comprehensive review of urban mining and the value recovery from e-waste materials. *Resources, Conservation and Recycling*, *190*, 106840. https://doi.org/10.1016/j.resconrec.2022.106840

Yohannessen, K., Pinto-Galleguillos, D., Parra-Giordano, D., Agost, A., Valdés, M., Smith, L. M., Galen, K., Arain, A., Rojas, F., Neitzel, R. L., & Ruiz-Rudolph, P. (2019). Health Assessment of Electronic Waste Workers in Chile: Participant Characterization. *International Journal of Environmental Research and Public Health*, *16*(3), 386. https://doi.org/10.3390/ijerph16030386

Yuan, H., & Shen, L. (2011). Trend of the research on construction and demolition waste management. *Waste Management*, *31*(4), 670–679. https://doi.org/10.1016/j.wasman.2010.10.030

Zavatti, J. R., García, S., Antolini, L., Carmona, P. D., Osuna, N., Malinovsky, V. A., & Finkelstein, J. Z. (2020). *Aplicación de la simulación de Montecarlo a la estimación de riesgo para la salud por exposición infantil a plomo en suelos contaminados de la Cuenca Matanza Riachuelo (Argentina)*. *20(2)*, 192–197. https://srala.org/wp-content/uploads/2019/02/ST15-01JZavatti.pdf

Zeng, X., Xiao, T., Xu, G., Albalghiti, E., Shan, G., & Li, J. (2022). Comparing the costs and benefits of virgin and urban mining. *Journal of Management Science and Engineering*, *7*(1), 98–106. https://doi.org/10.1016/j.jmse.2021.05.002

APPENDIX A
ADDITIONAL MATERIAL

A.1 E-waste-Related International Organizations, Associations, and Partnerships

Table A.1 List of some e-waste-related international organizations, associations, and partnerships.

Name of the project/organization	**Topic**	**Sector**	**Goals/Description**
E-waste Academy	E-waste	Academia - Program	The E-waste Academy provides tailored and targeted training for different stakeholder groups. It is a one-of-a-kind platform form for capacity building on e-waste.
GAIA	Waste and pollution	Nonprofit - Alliance	Catalyzes a global shift towards environmental justice by strengthening grassroots social movements that advance solutions to waste and pollution.
GESP: Global e-waste Statistics Partnership	E-waste	Int. org.- partnership	Improves and collect worldwide e-waste statistics in an internationally standardized way. Raises visibility on the importance of tracking e-waste. Delivers capacity building workshops.
GSMA	E-waste	Nonprofit - Industry	GSMA delivers for its members across three broad pillars: Industry Services and Solutions, Connectivity for Good, and Outreach.
PACE	Circular economy	Int. org. Program	Catalyzes global leadership from business, government, and civil society. Transforms knowledge into an evidence-based collective action agenda. Advances projects that are pioneering or scaling the circular economy.
SERI	E-waste	Nonprofit org	SERI is the only multi-stakeholder, collaborative nonprofit organization in the world focused exclusively on minimizing the environmental and health risks posed by used and end-of-life electronics, while also maximizing the social and economic value presented by this equipment.
SRI Sustainable Recycling Industries Programme	Informal Economy, Recycling	Nonprofit - Program	Recycling Initiatives: SRI improves local capacity for sustainable recycling together with private and public institutions, as well as the informal sector in Colombia, Egypt, Ghana, Peru and South Africa. SRI Roundtable: SRI aims at transferring the ISO-IWA 19 “Guidance Principles for the sustainable management of Secondary Metals,” which was developed by the SRI roundtable, into an official ISO standard.
StEP: Solving the E-waste Problem Initiative	E-waste	Nonprofit - Platform	StEP applies an integrated, science-rooted approach to create salient solutions to global e-waste challenges along the entire electronics life cycle.

Table A1. Continued

Name of the project/organization	**Topic**	**Sector**	**Goals/Description**
WEEE Forum: International Association of Electronic Waste Producer Responsibility Organizations	E-waste	Nonprofit - Producers	World's largest multi-national center of competence as regards operational know-how concerning the management of waste electrical and electronic equipment.
WIEGO: Women in Informal Employment: Globalizing and Organizing	Informal Economy, Women	Nonprofit - Network	WIEGO promotes change by improving statistics and expanding knowledge on the informal economy, building networks and capacity among informal worker organizations and, jointly with the networks and organizations, influencing local, national and international policies.
UNIDO-GEF PREAL Project, "Strengthening of National Initiatives and Enhancement of Regional Cooperation for the Environmentally Sound Management of POPs in WEEE"	E-waste	Int. Org. Project	Assists 13 Latin American countries both technically and financially, advising on e-waste policies and regulations, suitable management technologies, business models, capacity-building and awareness-raising.
RELAC: Plataforma Regional sobre Residuos Electrónicos de PC en Latinoamérica y el Caribe	E-waste	Nonprofit - Project	Prevention, refurbishment, recycling.
Latitude R	Recycling	Nonprofit - Platform	Regional initiative to coordinate actions, investment, and knowledge on inclusive recycling
LACRE: Red Latinoamericana y del Caribe de Recicladores	Recycling Informal Economy	Nonprofit - Network	Participates in initiatives, alliances and platforms and seeks to promote social, economic and environmental inclusion of workers
Avina Foundation	Various	Nonprofit - Foundation	CollaborAction: This framework is a type of social innovation that – along with "innovation with purpose" involving innovative technology and new business models.
Interamerican Foundation	Various	Nonprofit - Foundation	Finances projects of sustainable development in Latin America and the Caribbean.
Regional Initiative for the Economic and Social Inclusion of Recyclers	Recycling Informal Economy	Int. Org. Initiative	The Initiative is based on the experiences of projects in the region. It seeks to help incorporate recyclers into formal municipal or private waste management systems, to transform the recycling market, and to improve the socio-economic conditions of informal recyclers and their families in LAC.

A.2 General identification of chemical risks of e-waste management at Site A and Site B.

Table A.2 Preliminary identification of chemical risks of e-waste management at Site A and Site B.

Activity	**Site A**		**Site B**	
	Environment	**Health**	**Environment**	**Health**
Collection	Release of toxic leachates on the ground (batteries)	Dermal contact and inhalation (general EEE)	No identified	Dermal contact and inhalation (general EEE)
Storage	Release of toxic leachates (batteries). Microplastic pollution (general EEE)	Ingestion of contaminated food, Dermal contact & Inhalation (general EEE)	Potential fire-hazard from bearing parts and components (e.g., Li-Ion batteries)	Hazardous waste close to the eating area: Dermal contact & inhalation
Treatment	Soil contamination (general EEE)	Inhalation of toxic fumes and ingestion of contaminated food (cables). Dermal contact, inhalation, and dust ingestion with contaminants (CRT TVs). Take-home exposures.	Soil contamination (cables)	Inhalation of toxic fumes (cables). Dermal contact, inhalation, and dust ingestion with contaminants (CRT TVs). Take-home exposures.

A.3 Other General identification of chemical risks of e-waste management at Site A and Site B.

Table A.3 List of other EEE potentially burned at Site A and their components (not comprehensive).

Other EEE potentially burned at site A	**Components**	**Source**
Batteries	Heavy metals: Cd in Ni-Cd batteries, Pb in lead acid batteries, Hg in Hg batteries	Tsydenova & Bengtsson (2011)
Printed Circuit Boards	Pb (302 mg/L, according to Lora Reyes (2017)),Sb in solder Cd, Be in contacts Hg in switches BFRs in plastics.	Tsydenova & Bengtsson (2011)
CRT TVs	Flame retardants: Decabromodiphenyl ether technical mixture (DecaBDE) - Commonly used in electronics until around 2013. Heavy metals: Pb in cone glass (2-3 kg, according to Lora Reyes (2017), Cd in phosphors. Other metals: Ba in electron gun getter.	NIOSH, (2019). Tsydenova & Bengtsson (2011)

A.4 ACUMAR's EISAAR methodology

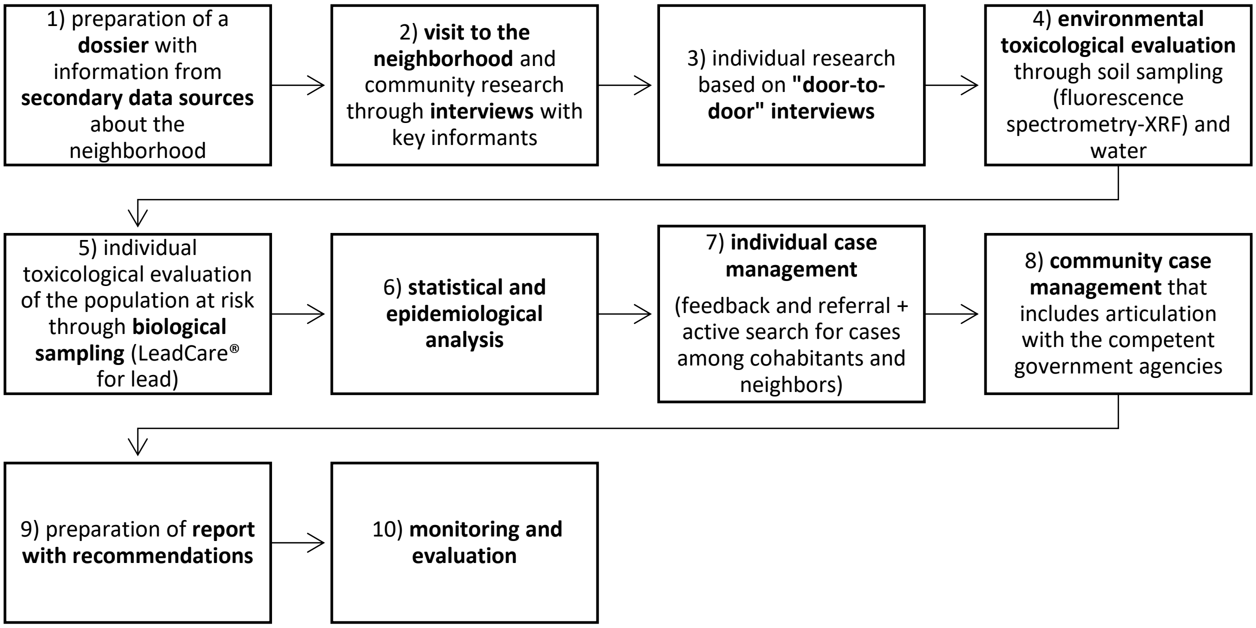

Figure A.1 Steps in ACUMAR's EISAAR methodology.

A.5 Suggested exposure descriptors for Sites A and B.

Table A.4 Suggested exposure descriptors for Sites A and B.

Site	Exposure time	Exposure frequency	Exposure duration	Average duration of exposure
A	0.5 hr/day. This is the average time it takes to burn an average amount of cables to get one kilogram of copper, as declared by some participants.	48 days/year (1 day/week). Since the burning of cables is not the main activity of these workers, it is estimated that, on average, they perform this activity once per week.	40 years (Kwarteng, 2022).	350,400 hr (40 years). (Kwarteng, 2022).
B	1 hr/day. This is the time assumed for recovering 1000 kg of copper in one day.	2 days/year. According to the workers, they used to burn cables as an extra income once or twice per year.	40 years (Kwarteng, 2022).	350,400 hr (40 years). (Kwarteng, 2022).

APPENDIX B
SUPPLEMENTAL FILES AND PERMISSIONS

B.1 Interviews guides may be found in Supplemental File B1Interviewsguides.docx

B.2 Approval Letter from the Human Subject Review Team at Colorado School of Mines may be found in Supplemental File B2SofiaSchlezakExemptionApprovalLetter.pdf

B.3 Amendment Letter from the Human Subject Review Team at Colorado School of Mines may be found in Supplemental File B3StyerSchlezakHSRAmendmentApproval1.27.23.pdf

B.4 Detailed sites visits description may be found in Supplemental File B4SiteVisits.docx

B.5 Pictures used during the workshop activities at Sites A and B may be found in Supplemental File B5PicturesWorkshop.docx

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