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Systematic Review

Analysis of the Past Seven Years of Waste-Related Doctoral Dissertations: A Digitalization and Consumer e-Waste Studies Mystery

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Abstract: Solving global sustainability challenges is based on a well-researched understanding of the corresponding underlying problems, key contributing factors, and current state-of-the-art. Utilizing the scope of recent doctoral studies is one potent way to map current young researchers nowadays and near future research focus areas and directions. Here, the authors focused on waste management, especially, mapping dissertations on the grooving global challenge of electronic waste. Currently, this is the first scoping study of its kind, about e-waste -related trends within the circle of waste management-related doctoral studies. Apparently, in a waste-related context, dissertations have a low interest in directly focusing on the topic of consumable e-waste, even though this waste stream is the world's fastest-growing domestic waste stream. Only a handful of doctoral dissertations, related to e-waste management, were found in the study. In a more general waste-related benchmarking/comparing mapping search, the ProQuest Digital Dissertations database was found to contain 201 dissertations between the years 2015 and 2022, covering waste matters in general. E-waste was covered in six of these 201 dissertations. These six did not have any real overlapping between each other and their research areas. Further thesis content analysis revealed e-waste topics to be currently addressed through consumer behavior, material recovery processes, forecasting, and robotics. The need for future research in the areas of consumable e-waste management is also widely discussed.

Keywords: electronic waste; e-waste; doctoral dissertations; Sustainable Development Goals; SDG; systematic literature review

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1. Introduction

The global waste issue is still challenging all continents quite heavily. The amount of generated waste is going up, even though different nations are applying real action against it [1]. By 2050, the municipal solid waste rate is estimated to reach 3.4 billion metric tons [2]. This increase is partly a result of global population growth, which boosts the total globally generated waste amounts [3]. On the population front, mankind reach the first billion in 1804, then it took over 100 years to get to the second billion (in 1927), the third billion in 1959, the fourth in 1974, and so on [4]. The growth rate has been basically exponential in nature but seemingly turning towards more stable and linear growth from the current population of around 8 billion people [5]. By the year 2030, the world population is predicted to reach 8.5 billion people [5,6]. At the same time, consumption per person is also going up [7]. Concerning the world population, the Kaza et al. [8] study indicated 0.74 kg of waste was generated per capita per day globally. Measures to fight against the waste issue, prevention, reduction, and recycling of waste are key ingredients are mentioned multiple times in Sustainable Development Goals (SDG hereinafter) as ideologies to address the most urgent world challenges [9]. As part of the actions to solve the waste and sustainability issues, countries [10,11], businesses [12–14], and universities [15,16] are facing a growing trend to

redefine their strategies and organizations to align to sustainability requirements through the SDGs lens. Practical actions to fight against waste and pollution generation have been carried out greatly in recent times. These include, e.g., factors influencing people's tendencies to separate waste properly [17], giving community members a chance to be part of environmental monitoring activities [18,19], empirical studies and experiences of using gamification to improve people's interests to separate waste [20], industrial emissions reduction through exhaust gasses scrubbers [21], fleet-level data sharing to enhance digital services [22], using digitalization to reduce emissions in warehousing activities [23] and reducing emissions through data analysis [24]. Since the European Waste Electrical and Electronic Equipment (WEEE) directive set targets for collection and subsequent processing of e-waste for material recovery [25], companies have become more committed to reducing WEEE waste through producers' responsibility legislation to improve recycling end-of-life products and take recycling into account in product design [26], and so on. To illustrate the escalating waste problem, the data from the Organization for Economic Cooperation and Development (OECD) countries was retrieved. Figure 1 provides a graph of OECD countries' population growth against municipal waste generated from 2005 to 2000 years. As can be seen, the municipal solid waste trend is still steadily growing regardless of the population number.

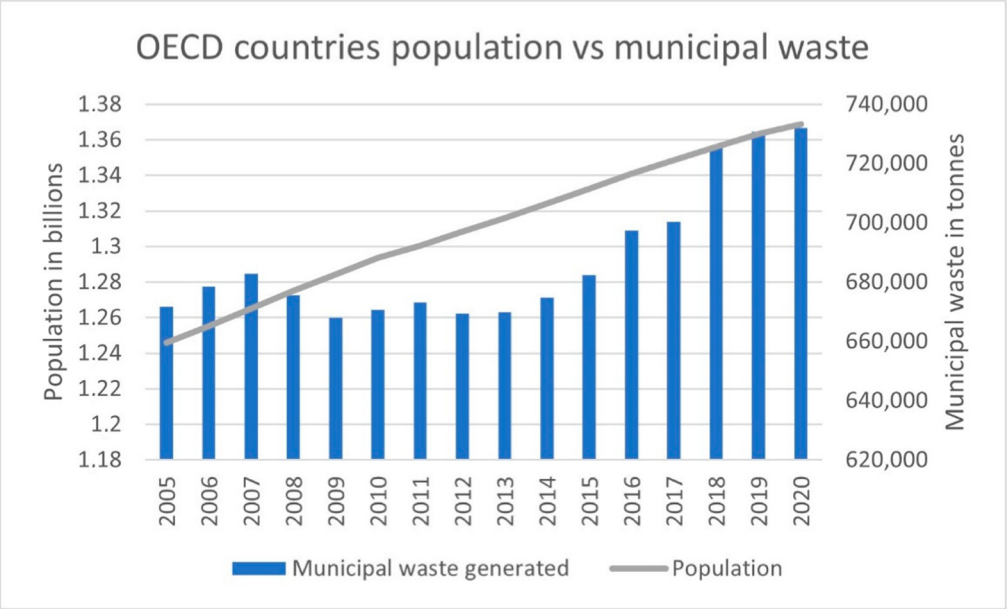

Figure 1. The annual population growth recorded in OECD countries vs. municipal waste is reflected in the graph (Data from OECD [27]).

As combined current realities, we are expected to have an increasing waste problem and increasing waste amounts [28] for the unforeseen future if the status quo is not changed, especially as many developing countries are going through similar industrialization, which happened earlier in developed countries. It is scientifically proven that a high gross domestic product of a country directly correlates with the amount of e-waste generated [29]. The population growth and wealth/resource consumption growth in developing countries is pushing the waste output up, even though there are actions taken in attempts to limit personal and industrial waste outputs [30]. In addition, as a global population, we are facing issues of eroding our natural resources as a sequel of perturbations in the environment due to rapid industrialization and population rise with the added problem of people having a reckless attitude towards the environment in general [31]. For example, as Chen et al. [1] projected from the waste generation dataset of 217 countries and regions, current sustainable waste treatment actions did not increase fast enough to be powerful enough in comparison with humankind's waste generation rates. To solve the issue, more data

is still needed about where the waste is generated to be able to target priority areas for the implementation of mitigation policies [32]. Generally speaking, waste is a critical and global problem that must be addressed now when we still can make a move [33–35]. This, in turn, means that the current trends in waste recycling cannot relieve pressure on the planet's natural resources in a fast enough way. This puts us under a pressure to achieve more circular economy in global scale, like a more balanced waste and sustainable living style and more direct policies, actions, incentives, novel technology innovations [36,37], technology to enhances and automate resourse collection [38], supplychains improvement on performance, gainsharing and green management practices [39–41] and so on. Currently, some of the worst predictions indicate that current negative trends will not go away, and the bad trend of our wasteful global lifestyle will not end until around the year 2100 [1,42,43]. Within the context of these trends, one of the big challenges we have is a global transition from traditional products to digitally enhanced products [44], i.e., the digitalization of everything and the constantly growing amount of related e-waste, which is growing around 3–5% per annum [45].

The overall structure of the research takes the form of five chapters, including this introductory part. The second section of this paper reviews the existing e-waste problem to be studied in this research work. The third chapter explains the collection process of doctoral dissertations continuing with the actual systematic literature review of doctoral dissertations (the fourth chapter). The fifth section starts from the overview part, in which the authors map the recent doctoral dissertations on waste-related study areas highlighting the lack of e-waste theses. The remaining part of this chapter is devoted to e-waste dissertations collection and analysis. The final chapter draws upon the entire article discussing the findings and implications for future research into this area. Finally, the conclusion gives a brief summary of areas for further research and critique of the findings.

2. E-Waste Problem Overview

In the 21st century, the amount of e-waste we generate is still highly increasing, and daily life-connected electronics are becoming a more and more integral part of human lives, especially with higher speeds in developing countries as well. It is hard to believe how people could move away from the archived level of convenience and start once again living without most of the electronics that they have become used to. Additionally, the speed of technological progress is so fast that many newish electronics do become obsolete faster than their usable life would indicate and as such, these items are changed/updated to new ones before they reach their end of usable life state [46]. Furthermore, as part of digital design [47] and digital transformation and digitalization of social services and participation models [19], many companies have moved to consumer-grade devices because of easier access and cheaper purchase prices. This change has made it easier and faster to change the devices to newer generations, but at the same time, the fast pace of change creates waves of technological disruption across multiple industries. At the same time, the obsolescence puzzle is becoming a focal issue for firms as well [48], especially SMEs, who go in the direction of utilization of consumer-grade devices. In addition to the natural development of electronics, big corporations are utilizing marketing and technology design practices such as planned obsolescence, which together are escalating and worsening the global e-waste problem [49]. Electronic waste as one of the common waste streams associated with economic development, urbanization, population growth, and increasing consumer demand has a prominent share in the (e-waste) stream with 0,02 kg of waste per capita per day [8]. According to the EPA [50], e-waste is defined as electronics at the end of their useful life that are then thrown away, donated, or processed for further recycling. According to Balde et al. [51] there are six categories of e-waste: temperature exchange cooling and heating equipment (such as refrigerators, air conditioners, etc.), screens and monitors (e.g., laptops, televisions, tablets, etc.), lamps (e.g., LED, fluorescent lamps, etc.), large-sized electric equipment (e.g., dishwashing and washing machines, electric stoves, printing machines, photovoltaic panels), small equipment (e.g., microwaves, kettles, electric

toys, medical devices, etc.) and small IT and telecommunication equipment (mobile phones, GPS, calculators and similar). Concerning consumer electronics, its technical innovation and development, a high volume of designs and models shorten electronics lifespan and accelerates the replacement of outdated electrical and electronic equipment [29,52,53]. Based on statistical analysis from the UN's Global E-waste Monitor 2020, e-waste is the world's fastest-growing domestic waste stream. The percentage growth/increase of e-waste from 2014 to 2019 is almost 21% (from 44.4 to 53,6 million metric tons (Mt) waste (excluding PV panels) [54]. This number is predicted to double by 2030 [8].

The amount of e-waste is constantly growing. In 2019, the amount of e-waste reached approximately more than 50 million metric tons [55,56] and most still do end up in landfills. As of 2021, there were 57.4 million metric tonnes of generated e-waste [57]. Currently, the generation of WEEE is increasing by 3–5% per annum [45]. Current overall ideologies for WEEE recycling are based on the following principles: (1) giving e-waste materials useful application through recycling and recovery of the items and their components; (2) extending the lifespan of the electronics and their components through reuse, repair, refurbishing, remanufacturing, and repurposing; (3) smart (re)use of the e-waste and manufacture via refuse, rethink, reduce [58]. In practice, the base principle of recycling e-waste is quite simple: crush and shred e-waste items into small granulates and then process to extract valuable materials from the tiny pieces. Metals can be separated with eddy currents and magnets, plastics float on liquids, and denser components will sink to the bottom of separators and so on. A typical e-waste item is a composite and combination of multiple different metals, plastics, polymers, and so on, and it could be harder to separate its valuable components than what those parts are worth. Partly because of the mentioned challenges, in the EU, less than 40% of e-waste is recycled by certified recyclers [59], whereas the rest of it is still not sorted [60]. Contamination resulting from improper recycling of e-waste (landfill) has already been damaging the environment and people's health [61–63]. Degradation and storage of e-waste scrap release hazardous materials that, in turn, pollute soil, air, and water [64]. Regular control and awareness of the waste stream facilitate the achievement of SDG and implementation of the ITU Connect 2030 Agenda [65].

As one of the current global development trends, the use of digital technologies has a real and relevant potential to provide more effective and more efficient waste management and circularity solutions by deploying the IoT [66,67], AI [68], smart bins [69], Industry 4.0 [70,71], robotics [72], and various other advance technologies to tackle the waste issue [73]. However, the dark side of ongoing digitalization is that it can highly increase demand for electronics, technological devices, and equipment, which can be seen as an unsustainable part of digitalization [74]. On one hand, as Aksin-Sivrikaya and Bhatt [75] say, "As a result of digitalization, we are bound to use electronic devices", whereas, on the other hand, digitalization can be used as a tool to fight against the waste problem, e.g., through gamification and digitally enhanced sustainable business models [20,76].

3. Methodology

The methodology section presents the detailed purpose of the study and describes the used research methods and tools. Additionally, the section also explains the focus and selection of literature reviewed in the study.

3.1. Systematic Literature Review

The study addresses the gap in consumer e-waste-related research, utilizing a systematic literature review (SLR hereinafter) [77] of the English language area-specific doctoral dissertation. Traditionally, a doctoral dissertation can take formats of either a monograph or a dissertation consisting of multi-authored publications [78]. The last one can be referred to as a publication-based thesis which can consist of a series of peer-reviewed academic papers (such as refereed or non-refereed articles in journals, conference proceedings, and book chapters) [79]. By definition, the majority of doctoral dissertations are published in the peer-reviewed scientific literature; however, they only eventually contribute to peer-

reviewed literature due to issues of long revision and resubmission, methodology rigor, etc., as raised by Evans et al. [80]. Nicholas et al. [81] conclude that in the digital age, young researchers (30 years and younger) do not tend to trust peer-reviewed journals as much as older colleagues do as informational sources and publication outlets. At the same time, Sakai [82] proves that young researchers prefer to make peer-reviewed publications robust in the early stages of their academic careers. Both peer and non-peer-reviewed literature can be analyzed "to identify deficits in the knowledge base" [83,84].

The current study is specifically designed to discover the current study trends in e-waste dissertations, evaluate and analyze possible research gaps, and map the last seven years. Further, the study discovered the content of dissertations devoted to consumer e-waste.

Studying dissertations publications published by research institutions is a useful way to understand the research scholar's early years of research focus areas. For instance, several researchers regard dissertation research and trends as a measurement of research progress and paradigm development [85,86]. Additionally, through studying the recent past, we build our general knowledge for the near future, expecting new knowledge and the number of contributions to be assumed to be available to us [87]. Doctoral dissertations can enrich the existing body of knowledge [88]. Andersen and Hammarfelt [89] have based their research on the seminal study of De Solla Prince about Ph.D. dissertations as a scientific growth indicator. Andersen and Hammarfelt [89] believe in the importance of the longitudinal study to understand research historical and contemporary developments.

3.2. Dissertation Collection

The collection of e-waste dissertations is based on SLR methodology. SLR allows an analysis of literature in a transparent and reproducible manner with predefined process steps [90] being at the top of the hierarchy of research evidence [91] and is a recommended EBSE method for evidence aggregation [77]. According to Kitchenham [92], SLR also helps to identify, evaluate, and interpret "all available research relevant to a particular research question, or topic area, or phenomenon of interest". SLR can "lie at the heart of pragmatic management research" to advance both academic and practitioner communities by providing a rigorous process of theoretical synthesis of already published literature on the topic [93], as SLR is a process that allows for the collection of relevant evidence on the given topic that fits the pre-specified eligibility criteria [94].

ProQuest Dissertation and Theses Global database is used to extract theses and dissertations on the topic. This database is acknowledged to have the most updated worldwide research works [95]. Additionally, the ProQuest dissertation was searched in default to ABI/INFORM Collection, Accounting, Tax and Banking Collection, Business Market Research Collection, Canadian Business and Current Affairs Database, Coronavirus Research Database, Ebook Central, Publicly Available Content Database, and Technology Collection.

The preference to search the ProQuest database is based on the database's special distinction search via theses and dissertations. In addition, ProQuest is acknowledged as one of 14 databases for effectively and efficiently searching for systematic reviews from 28 widely used academic search systems based on the research of Gusenbauer and Haddaway [96]. In this study, the authors assessed the suitability of 28 search systems for systematic reviews with 27 test criteria. Other databases, as mentioned in Table 1, evaluated for dissertations search were Web of Science (Core Collection), EThOS (e-theses online service), DART-Europe E-theses Portal, EBSCO open dissertations, Open Access Theses, and Dissertations. However, these databases were omitted as they did not provide the thesis classification capabilities needed for the study.

Table 1. Database names and links.

THE DATABASE	WEBSITE LINK (accessed on 8 May 2022)
ProQuest Dissertation and Theses Global	https://about.proquest.com/en/products-services/pqdtglobal/
Web of Science (Core Collection)	https://www.webofscience.com/wos/
EThOS	https://ethos.bl.uk/Home.do
DART-Europe	https://www.dart-europe.org/basic-search.php
EBSCO	https://biblioboard.com/opendissertations/
Open Access Theses and Dissertations	https://oatd.org/

Concerning the SLR, we implemented the main steps from Čablová et al.'s [97] research using the development of a previously published review as an example of good practice that, (1) defines the research aim, (2) provides data sources identification, (3) determines selection criteria, (4) collects data, and (5) interprets results. SLR helps both in framing the research and also in gathering relevant literature for a content study. By employing content analysis of dissertations, our study covers, and maps dissertation knowledge that has not been covered in previous studies [98]. The data collection is presented in SLR study flow diagram form, following the Prisma process. Prisma stands for Preferred Reporting Items for Systematic Reviews and Meta-Analyses. PRISMA offers an effective way of improving the quality of reporting systematic reviews [99].

4. E-Waste Dissertations Data Collection

The data collection chapter examines the general topic coverage of waste management theses and moves on to the discussion of the existing gap in e-waste doctoral research.

4.1. Overview of Doctoral Theses about Waste Management

The work started with a database search for "waste management" with the utilization of the ProQuest database. This starting point revealed a few thousand dissertations (3557) based on the search dated 9 May 2022 from the ProQuest database. The database tools offered a special grouped view of the existing dissertations based on the index subject area coverage in the database. All lists of subjects from ProQuest, with the corresponding number of dissertations contributing to those areas, are presented in Appendix A. As any of these publications can contribute to multiple subject areas at once, the number of contributions will be higher than the total number of existing dissertations.

In the high-level findings, the largest classified groups were research studies (research methodology, literature reviews, qualitative research, etc.), business management and administration (e.g., management, business management organizational behavior, corporate culture, etc.), economics (e.g., economic growth, economics, economic theory, etc.), finance (e.g., costs, costs control, accounting, etc.), engineering (engineering, civil engineering, biomedical engineering, chemical engineering, electrical engineering, environmental engineering, mechanical engineering, industrial engineering), politics (e.g., politics, public administration, public policy, political science, etc.), education (etc. education, higher education, educational leadership, business education), and so on.

Interestingly, digital design [100], digitalization [101], and digital transformation [44] megatrends such as information technologies (e.g., computer science, information and communication technology, information technology software, etc.) are not so popular compared to the previously mentioned subjects in waste-related doctoral dissertations. Additionally, it was noticed that the current prominent growing waste-related problem area of electronic waste (e-waste) did not gather its own separate subject category in ProQuest, even when e-Waste itself is a big global problem [102]. Some sustainability-related topics such as environmental impact, protection, pollution, etc. can definitely be easily noticed, but they are not at the top of the most popular subjects either. On the contrary, the

bibliometric analysis of Gao et al. [103] shows that e-waste, in general, is a hot topic, and it is widely studied by scholars. The study of Gao et al. [103] already indicated a global interest towards e-waste-related studies, with rapidly increasing academic publication outputs since 2004. However, the outputs seem to be almost lacking totally on the side of the doctoral dissertation and there have not been any systematic review studies of the number and/or content of doctoral dissertations in the field of e-waste, whereas dissertation research provides a view on the conceptual and empirical contributions to the field [104]. Given all the previously mentioned indications of the research gap of e-waste within doctoral dissertations, this work answers the challenge to evaluate the current research gap size and explains the reasons for the status quo. In this process, we started with the overview of the e-waste problems scale and followed through with the methodology of mapping the current doctoral dissertations scale and the scope of the e-waste context.

4.2. E-Waste Dissertations Data Collection

In SLR, a proper selection of keywords allows for the inclusion of studies that strongly contribute to the search results [93,97]. The goal was wide-scale findings at the start and a good baseline in keywords. For an e-waste definition, EPA [50] was referred to when including the keywords "e-waste", "electronic waste", "e-scrap", and "end-of-life electronics". Moreover, the abbreviation "weee" and its full meaning of "waste electrical and electronic equipment" were added to the keywords list. These keywords widened the search scope by resulting in dissertations that referred to the EU Directive 2012/19 to contribute to sustainable production and consumption of electrical and electronic equipment [105].

A Booleans operator (OR) was used to find all possible dissertations addressing e-waste research with the list of selected keywords [106]. In addition, both singular and plural keywords were searched in the database. The set of keywords used is presented in Table 2.

Table 2. The list of keywords searched in ProQuest Dissertation and Thesis database.

THE LIST OF E-WASTE RELATED KEYWORDS
"e-waste" OR *"e-wastes"* OR *"electronic waste"* OR *"electronic wastes"* OR *"end-of-life electronic"* OR *"end-of-life electronics"* OR *"e-scrap"* OR *"waste electrical and electronic equipment"* OR *"weee"* OR *"end-of-life electronic waste"*

For the dissertation search, we used the default search in ProQuest. This search includes all document properties indexed in the ProQuest [107] database. Using these keywords, the research started its SLR following the Prisma model, as presented in Figure 2. As shown in the table, the search of keywords in ProQuest dissertations and theses database with both filters of the English language applied and publication date from 1 January 2015 to 1 March 2022 yielded 201 results of dissertations published in the English language.

The analysis of the dissertations titles and abstracts ended up excluding 178 dissertations (approximately 88% from the preliminary dissertation search). Mainly, the excluded dissertations only partially mentioned e-waste in a few clauses or other similar references which did not produce any true new insight into the issue at hand. Moreover, such excluded dissertations studied e-waste management from the industrial point of view (e.g., transformers in end-of-life sea vessels or in nuclear plants) rather than discussing issues associated with consumer//end user-related e-waste. In addition, dissertations that attempted to cover political, economic, and sustainable aspects of waste management were not considered for this search. Quite a few dissertations in their abstracts examined and accessed current end-of-life strategies for waste management for economic costs and environmental impacts. Additionally, we were able to find specific words that helped to detect dissertations that are out of the focus (consumable e-waste) of this search. Examples of such words from abstracts that were not considered for further analysis are gathered in Table 3.

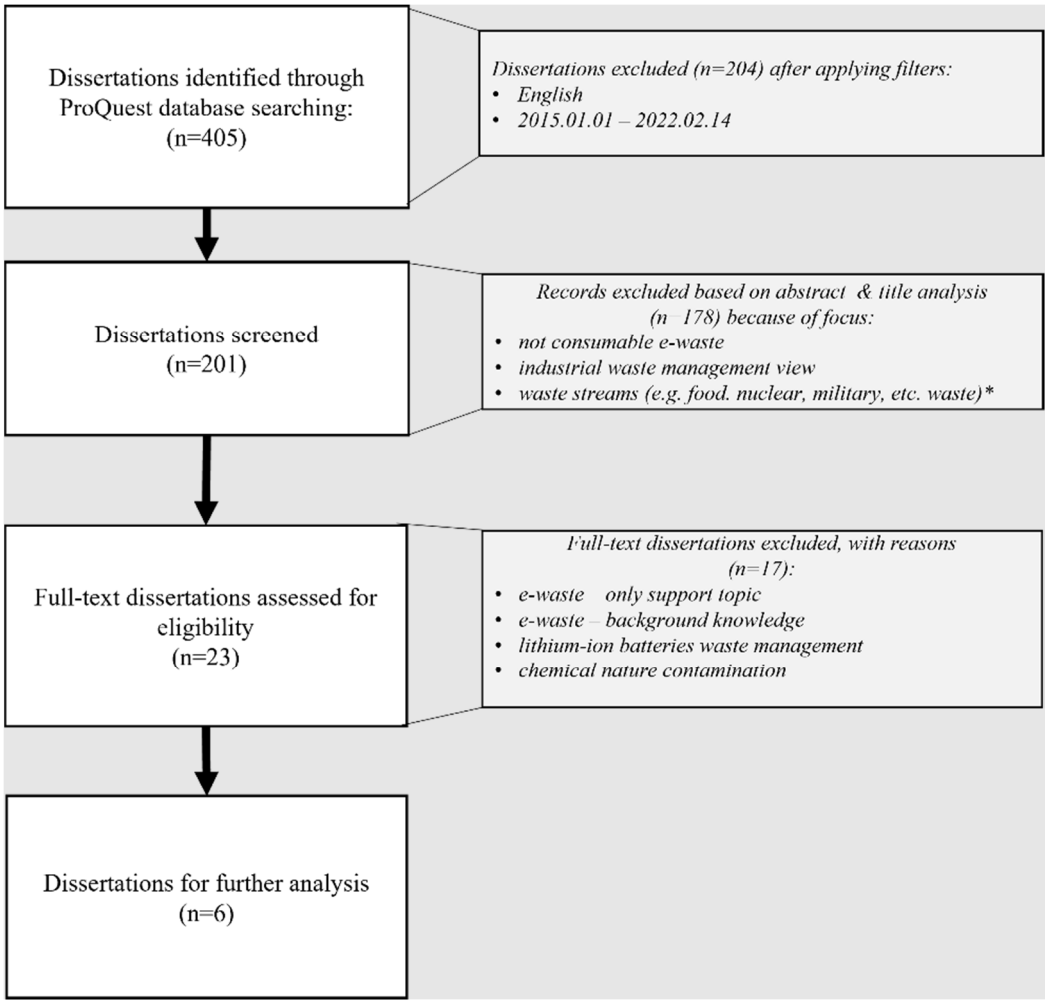

Figure 2. PRISMA study flow diagram synthesized from [97,99].

Table 3. Examples of words that were not in the core focus of this study (consumable e-waste) and not considered in the screening phase of SLR.

Waste-to-energy	Organic/Biowaste	Wastewater	Military waste
Food waste	Marine waste	Nuclear waste	Mining waste
Medicine waste	Jail waste	Telecommunication infrastructure waste	Construction waste

In the studies' eligibility assessment (full-text reading), around 75% (17) of dissertations were rejected. The reason for rejection was that in the rejected studies, e-waste was still a side topic (not the main research focus area). In these studies, e-waste was mentioned only a couple of times, as a piece of background knowledge. Additionally, dissertations about degradation and biodegradation of batteries and chemical contaminations from lithium-ion batteries pyrolysis were also excluded, as these did not focus on the issue of consumable e-waste. Finally, six dissertations were selected to be consistent with the selected research objective.

5. Findings

In the last seven years, six doctoral dissertations on the e-waste subject were published and presented in the ProQuest database index. The number of studies per year is presented in Figure 3.

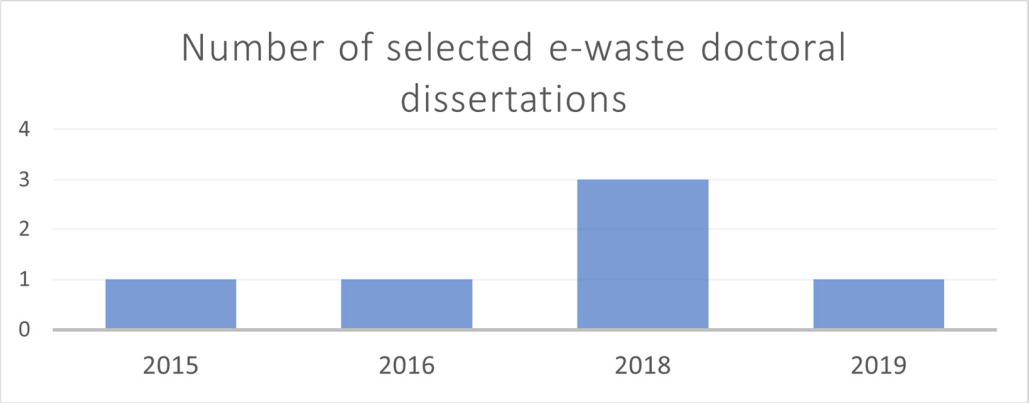

Figure 3. The number of selected for review e-waste doctoral dissertations published in recent years.

The results obtained from the content analysis of the existing doctoral dissertations are quite heterogeneous, as shown in the content-based division presented in Table 4. The collection table presents each dissertation's research aim.

Table 4. The research aim of six e-waste doctoral dissertations.

DOCTORAL DISSERTATION	RESEARCH AIM
Isaacs, S.M., [108]. Consumer perceptions of eco-friendly products	To discover the role of buyers' desires to participate in products recovery
Mashhadi, A.R. [109]. Improving the Effectiveness of End-of-Use Product Recovery: Operations Planning	To research uncertainties associated with consumers' return, usage, and repair behavior to improve products recovery rates
Cui, H., [110]. Hydrometallurgical Treatment of E-scrap	To investigate the feasible way of recovery of hydrometallurgically valuable metals with the help of bromine from waste printed circuit boards
Huang, W.H. [111]. Recycling Valuable Materials from Crystalline-Si Solar Modules.	To propose sustainable recycling of c-Si modules
DiFilippo, N.M. [112]. Framework for the automated disassembly of electronic waste using the Soar cognitive architecture.	To integrate the Soar cognitive architecture into robotics to disassemble e-waste on an automatic basis
Ashraf, A.M. [113] Forecast Model for Return Quality in Reverse Logistics Networks	To propose a forecast model capable of predicting the amount of returned electronics

One of the main focuses discussed throughout the dissertations is consumer behavior regarding e-waste (two dissertations). Firstly, Isaacs [108] examines through the prism of consumer and buying theories the desires of buyers to overpay for more environmentally sound electronics. Based on the results, pilot test participants would continue to buy the disposable brand if the price increases; however, some people would not wish to give up their electronic devices for recycling despite access to more drop-off recycling centers.

In the second dissertation on a similar topic, Mashhadi [109] defines all uncertainties associated with end-of-life recovery processes and consumer behavior. After studying consumers' returns, usage, and repair behaviors as parts of the product lifecycle, the author creates an agent-based simulation framework to build a consumer behavioral model. The authors conclude the cruciality of the product design to guarantee a proper level of product recovery. Mashhadi [109] does not discuss so much e-waste management as in the previous dissertation but mentions electronic waste as an example of end-of-life products. On consmable electronics life cycle side, Ashraf [113] proposes a forecast model to estimate the remaining useful life of returned consumable electronic products and their components,

the associated repair costs, and the subsequent profitability of reprocessing based on the economic value in the market.

For chemical elements recovery, Cui [110] reviews electric and electronic wastes and introduces a study to recover valuable elements from the leaching solution. However, the process was evaluated as not economically feasible, and the author recommends further studies to dissolve precious metals with bromine and sodium bromide.

Continuing the line of e-waste sustainability, Huang [111] introduces a technical and environmentally, and financially sustainable recycling process for crystalline-Si solar modules. Furthermore, in the dissertation by DiFilippo [112], the robotics and soar cognitive architecture system is studied in automatic mode to help to locate screws in the backside of laptops and remove them, whereas, generally, unscrewing is considered the initial step in complicated e-waste recycling. Thus, this paper is selected to add to the pull of e-waste management research.

In summary, we attempted to map the context of these dissertations from their subject areas' point of view to see whether there is any specific pattern and/or overlap in the thesis focus areas. For this, analysis from ProQuest Dissertation and Theses database was used to compare these publications to each other. First of all, dissertations from Isaacs [108] and Mashhadi [109] cover several disciplines such as sustainable education and consumer behavior. All other dissertations are more specific and narrow view-focused. These four dissertations focus on a couple of areas, such as education, IT, and engineering. From the topics' point of view, only mechanical engineering and sustainability were found to be mentioned in more than one dissertation as focus areas. In short, there does not seem to be any specific trend to make a wide or narrow field thesis in the e-waste sphere. Moreover, all existing theses are currently widely different in their scope, leaving many possibilities for future theses to cover as well. The following Table 5 shows the summary of the ProQuest subject area analysis.

Table 5. Subject areas defined by ProQuest for six doctoral dissertations.

SUBJECTS	*Isaacs, S. M. [108]. Consumer perceptions of eco-friendly products*	*Mashhadi, A. R. [109]. Improving the effectiveness of end-of-use product recovery: Operations planning, consumer behavior and design guidelines*	*Cui, H. [110]. Hydrometallurgical treatment of e-scrap*	*Huang, W. [111]. Recycling valuable materials from crystalline-si solar modules*	*DiFilippo, N. M. [112]. Framework for the automated disassembly of electronic waste using the soar cognitive architecture*	*Ashraf, A. M. [113]. Forecast model for return quality in reverse logistics networks*
Brand loyalty	X					
Business administration	X					
Canadian studies						X
Chemical engineering			X			
Consumer behavior		X				
Consumers		X				
Decision making		X				

Table 5. *Cont.*

SUBJECTS	*Isaacs, S. M. [108]. Consumer perceptions of eco-friendly products*	*Mashhadi, A. R. [109]. Improving the effectiveness of end-of-use product recovery: Operations planning, consumer behavior and design guidelines*	*Cui, H. [110]. Hydrometallurgical treatment of e-scrap*	*Huang, W. [111]. Recycling valuable materials from crystalline-si solar modules*	*DiFilippo, N. M. [112]. Framework for the automated disassembly of electronic waste using the soar cognitive architecture*	*Ashraf, A. M. [113]. Forecast model for return quality in reverse logistics networks*
Engineering			X			
Environmental education	X					
Environmental impact	X					
Industrial engineering						X
Information technology	X					
Management		X				
Marketing	X					
Materials science				X		
Mechanical engineering		X			X	
Mechanics					X	
OEM		X				
Perceptions	X					
Personal computers		X				
Product design		X				
Product returns		X				
Profits		X				
Purchasing	X					
Recycling		X				
Remanufacturing		X				
Sustainability	X					X
Trends		X				
Web Studies					X	

6. Discussion

Our work assesses the level/existence of e-waste doctoral thesis dissertations. In reviewing the literature, surprisingly few (basically only six doctoral theses) were found to truly focus on the matter of e-waste. This finding was unexpected and leads to the question: why there are so few e-waste-related dissertations at the moment? One pragmatic explanation for this phenomenon could be that the e-waste topic area is currently underfunded at the dissertation studies level. Furthermore, guiding professors may see the study area as too challenging for young researchers to focus on, but that hypothesis seems

unfeasible in current highly digitalized global economies that produce a great amount of digitalization-related devices such as e-waste. Perhaps the current research investigation was limited by doctoral thesis classification in the ProQuest database; however, on the general level, there was a huge group of dissertations covering waste topics in general. ProQuest database currently returns 3557 results on the topic of "waste management".

In summary, to be able to study the current situation of e-waste topic-related dissertations statuses in an academic doctoral studies context, several rounds of searches were run in various academic databases. These databases include, e.g., Scopus, Web of Science Core Collection, and ACM—Association for Computing Machinery databases. For the test search, the same set of keywords was utilized for all databases. The keywords utilized are presented in Table 2. The interest was given to the number of publications in these databases and the number of publications per year, to evaluate the growth of the academic output. The studies selected for investigation were limited to dissertations, which were published using the English language; in addition, results from all years were compared to results starting from the year 2000. We were mainly interested to discover e-waste-related research statuses (not only doctoral dissertations but in general). Table 6 depicts the total number of findings in this comparison search.

Table 6. The number of publications in databases is based on the set of e-waste keywords.

DATABASE	Total	English	Only Years 2000–2021
Scopus	12,055	11,667	10,173
Web of Science	5972	5865	5846
ACM	332	332	311

Figure 4 illustrates the growth of outputs as publications in each database separately. With the data, we wanted to discover the growth of academic e-waste-related output to the interest/among of existence dissertations in the same topic area. Looking at this graph, an exponentially steady growing trend can be easily noticed which, in turn, indicates the growing interest towards this topic in general. The number of publications, from 2000 to 2005, seems to first have a slower period, changing to a faster phase between 2006 to 2014 and then gaining speed again for the period from 2015 onwards. As the last growth spike is now 6–7 years in length, it could indicate that we shall start to see more e-waste-related doctoral dissertations soon to be finalized. If the beforementioned is the case, the current low number of doctoral dissertations is related to low overall academic total output in this area in recent history.

What is interesting in waste management-related research is that there has not been any dissertation analysis of dissertations done on this topic. More research as doctoral theses is expected to be seen in the near future, as the e-waste problem is still escalating widely. Due to the revolution of information technologies and the relatively short lifespan of electronics, compared to purely mechanical solutions, especially nowadays with constant technological updates and short usable life, the production of electronic devices has increased significantly. Consequently, this has increased the demand for electronics materials and components which, in turn, explains doctoral theses that focus on materials recovery [114]. Additionally, it is known that funding can drive research directions and can have a significant role in the academy [115], e.g., supporting research projects to solve scientific problems [116]. Lately, according to Borthakur and Singh [117], Chinese universities have received additional funding for e-waste-related research. Gao et al. [103] also suggest that China should cooperate in research with developed countries to increase research output in this direction. Based on the work done by Zhang et al. [118], nearly 70% of all e-waste generated in the world is actually processed in this country.

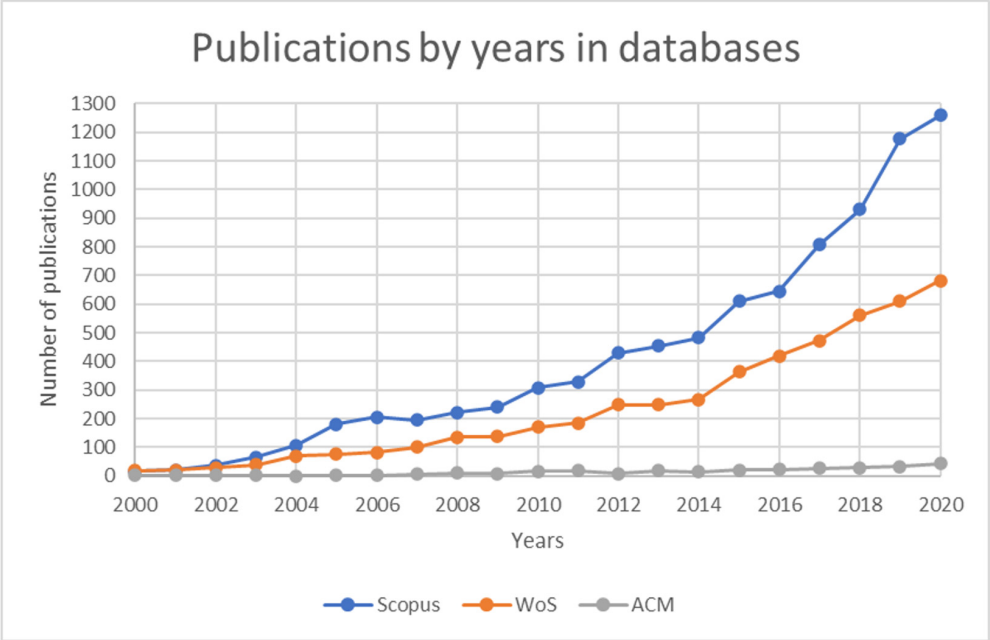

Figure 4. Publications in various databases based on e-waste keywords search.

Meanwhile, to predict an increasing quantity of e-waste manufacturing and such returns, some researchers suggest working on consumer behavior at this point. Lepawsky, a professor of geography at a Canadian university has rightly pinpointed that waste and pollution associated with electronics occur before people start to use their mobile phones [119]. For instance, a common charger for a USB Type-C port for portal devices can help to reduce redundant cables and chargers to save not only the environment but facilitate re-using of old devices, saving money for both consumers and businesses [120]. This can support the finding of Mashhadi's [109] dissertation, in which the author underlines the importance of product design in its recovery at the end of life to lead to corresponding consumer behavior. Such activities associated with extracting raw materials involve high consumption levels of electricity, hazardous chemicals, and water and the production of greenhouse gas emissions and further pollution [121].

Huang's [111] dissertation approached the problem of e-waste from its end-of-life edge. The author introduces a technical and environmentally and financially sustainable recycling process for crystalline-Si solar modules. Typically, PV is not considered a consumable electronic; however, in light of the current increasing prices of electricity, many people install solar panels on the top of their roofs [122,123]. Becoming an increasingly important alternative energy source, solar energy technology is currently the third most used renewable energy source worldwide [124]. Additionally, among PV cell types, c-Si solar cell occupies more than 80% of the market [125], and the process of handling c-Si solar modules as a source of hazardous e-waste should be addressed.

7. Conclusions

As of growing global sustainability-related pressures, the recognition of consumable e-waste is important to tackle and mitigate/limit the global environmental problem. The present research was designed to address the existing research gap on young researchers' focus in the context of e-waste through related doctoral dissertations analysis. Our work examined current e-waste research in doctoral studies and, additionally, current research directions were evaluated and analyzed too. Very few contributing (only six) dissertations were found to be present in the extracted 201 dissertations present in the ProQuest Dissertation and Thesis database. The extraction followed Prisma model-based SLR processes to gather all relevant existing knowledge of e-waste-related doctoral thesis research. The

mentioned six dissertations addressed the topic of e-waste through the prism of consumer behavior, material recovery processes, forecasting, and robotics research.

Consumer behavior studies in dissertations look to improve the recycling and recovery rate of e-waste. Authors found that customers are only ready to pay more for environmentally friendly electronics, in case of products, with which they are familiar and which are common to these people. Furthermore, people are reluctant to give up or transport their old electronics, despite easy accessibility, as it is mostly free to drop off used electronics at collection points. The e-waste recovery rate can still be increased with thoughtful and proper design, which will make it easier to return electronics to recycling points and recycle them more easily as well. Lastly, it was concluded that by studying customer behavior, new solutions can be offered to our currently escalating e-waste problem.

E-waste sustainability is additionally addressed by the recovery and recycling of material used for the production of new electronics from the old ones with chemical processes-based recovery and engineering solutions. However, the economic feasibility of such solutions is still in need of further studies to prove the feasibility of the complex concepts. Another direction for recovery is more mechanical-based solutions; in this particular thesis context, it was the usage of robotics to disassemble e-waste products to base components to ease up their further recyclability. Last but not least, young researchers have applied various simulation and forecast models to predict returned electronics and assess the feasibility of their re-treatment.

In general, such heterogeneous focused research areas leave much on the table for new directions of research. There is a lot of room for future doctoral theses with wider research spheres in the e-waste context. The number of existing dissertations is quite small to make a further generalization of results, but it can already be said that currently, only a minimal amount of young researchers start their academic careers in this specific context. The obvious finding, which emerged from this research, was the mysteriously low number of e-waste doctoral dissertations and theses, which were analyzed in the discussion part. Taken together, the authors provide pragmatic explanations for this phenomenon, promote further research in e-waste, and predict an increase in the number of e-waste-related doctoral dissertations in the near future.

Even though digitalization has provided new tools in waste separation/waste processing facilities, and as such has also improved recycling rates, at the same time "digitalization of everything" has produced huge loads of electronic waste to be processed and handled in a consumables waste items context. Academic theses with minimal effort in studying this issue and also peer-reviewed publications contribute less on the matter than the size of the e-waste problem would probably deserve. In further research, we suggest deeper mapping of peer-reviewed e-waste-related studies, their related mapping studies and citation analysis [71,126] and more generalized studies to identify the current biggest gaps and also to build an understanding of why this issue does not receive more coverage on any academic research levels and in study contexts.

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Appendix A. ProQuest Categorization of "Waste Management" Dissertations Based On Subjects

SUBJECTS	PUBLICATIONS	SUBJECTS	PUBLICATIONS
studies	1057	politics	103
management	659	cost control	102
environmental science	407	profitability	102
economics	353	economic development	100
decision making	319	profits	100
environmental engineering	312	developing countries–ldcs	91
civil engineering	311	collaboration	90
sustainability	287	geography	89
agricultural economics	244	economic theory	88
copyright	242	households	88
business administration	225	society	87
employees	221	corporate culture	84
hypotheses	199	industrial engineering	84
employment	184	political science	82
costs	166	consumption	81
agriculture	165	product development	81
environmental management	163	environmental economics	80
manufacturing	161	mechanical engineering	80
research	160	population	80
public administration	159	communication	79
research methodology	156	statistics	79
accounting	155	agricultural production	78
marketing	153	models	78
competitive advantage	148	business to business commerce	77
energy	148	dissertations & theses	77
engineering	147	information technology	75
public policy	147	air pollution	73
social responsibility	146	environmental policy	73
environmental impact	142	investments	73
environmental protection	139	compliance	72
competition	138	data collection	72
materials science	133	values	71
perceptions	125	regulation	69

leadership	124	social structure	69
urban planning	124	education	67
finance	123	emissions	67
climate change	120	recycling	67
trends	120	success	67
innovations	118	essays	66
case studies	116	ethics	66
chemical engineering	115	literature reviews	66
organizational behavior	113	behavior	64
economic growth	112	strategic management	64
public health	111	area planning & development	63
variables	111	health care management	63
sustainable development	110	computer science	62
natural resources	108	software	62
productivity	106	stock exchanges	62
chemistry	104	attitudes	61
design	103	ecology	60

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