UNCERTAINTIES IN THE RECYCLING OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT: A LITERATURE REVIEW

[1]ALICE FRANTZ SCHNEIDER, [2]MARIO SERGIO SALERNO

Master student in Production Engineering at Polytechnic School of the University of São Paulo – USP, Full Professor at Polytechnic School of the University of São Paulo – USP
Email: alice.afs@usp.br, msalerno@usp.br

Abstract—A systematic literature search has been conducted at the intersection of e-waste and uncertainty and the main uncertainties identified have been categorized. The main uncertainties identified were: Different recycling technologies; unknown environmental impacts; different product design and composition; unknown reverse logistics costs; variable cost of recycling; rapidly changing nature of electrical and electronic equipment; unpredictability about return of items concerning quantity, quality and timing; unknown destination flow of e-waste; different value of scrap materials; competition between the manufacturer and the remanufacturer; no common legislation at the national and global level; outdated political aspects; and complexity of regulations.

Keywords—e-waste, Innovation, Sustainability.

I. INTRODUCTION

Innovation is not a new concept. Taking into account the natural behavior of thinking about new and better ways of doing things and putting them into practice throughout history, it has arguably taken part in the evolution of humanity.

For reference [1], innovation started to be considered a separated field of research in the 1960s and, since then, it has gained strength in an environment of economic and social change. The subject of innovation requires a combination of insights from several disciplines and from different perspectives. It is, thus, a multidisciplinary and systemic phenomenon, representing the continuing interaction of different organizations and actors.

Innovation is defined, according to Michael Porter (1990 apud [2, p. 8]), as "[…] to include both improvements in technology and better methods or ways of doing things. It can be manifested in product changes, process changes, new approaches to marketing, new forms of distribution, and new concepts of scope . . . [innovation] results as much from organizational learning as from formal R&D".

There are several factors that create the need for innovation, which may be summarized as "technological advances, changing customers, intensified competition and the changing business environment"[2, p.2]. The first driver makes the creation of knowledge to happen at a large speed, which requires from the firms to monitor constantly the new technologies in order to maintain themselves competitive on the markets. The changing customers and needs concern the disappearance of traditional market segments and the need for companies to adjust their products and services accordingly. The third factor, intensified competition, occurs mainly in response of globalization, with the decrease of logistics costs and the increase of foreign competition. The last driver presented by [2] is the changing business environment and is directly connected with the worldwide open market economy and the short product life-cycles.

The innovation drivers presented by [2]can be easily connected with the electronic industry and the electronic waste (e-waste) recycling situation. Technological advances have made the consumption of electronics grow in a fast scale. As a result, those products' life cycle has been falling in the same proportion and today represents a worldwide trend. Products that used to last for a long time and were hardly disposed of are now renewed within a remarkable short time. Globalization and internet purchasing also exacerbates the problem, so that customers have access to a vast array of new products from different companies around the world. Whereas innovation is strongly present in new electronic products, there is a need to innovate in the reverse cycle as well, in order to tackle the objective of a sustainable development.

Considered for a long time innovation as a random phenomenon, Schumpeter has developed an original approach against this practice, stating that economic and social development is a process of change and driven by innovation. He has presented three main aspects that must be considered in innovation: the need to tackle inertia; the need to innovate before competitors to benefit from the potential economic reward; and the uncertainty in all innovation projects. The last two aspects are strongly linked with entrepreneurship, demanding qualities such as leadership and vision (Schumpeter, 1934 apud [1]).

II. UNCERTAINTIES AND COMPLEXITY

Reference [3] argues that managing a business today involves a much higher level of complexity than some years ago. Although complex systems have always existed, they have expanded from large systems to most of organizations nowadays, as result mainly from the information technology revolution. Complex organizations involve a high level of unpredictability and an unexpected interaction between systems. "Although single constituents may not remain in place and may eventually disappear, the system persists as it adapts to internal and external change" [4, p.444].

Whereas in complicated systems is possible to predict outcomes when the starting conditions are known, in complex systems there may be different outcomes due to the interactions of elements from the system, as presented by [3] - [4]. "Three properties determine the complexity of an environment. The first, multiplicity, refers to the number of potentially interacting elements. The second, interdependence, relates to how connected those elements are. The third, diversity, has to do with the degree of their heterogeneity. The greater the multiplicity, interdependence, and diversity, the greater the complexity"[3, p.70].

When dealing with collection and treatment of Waste Electrical and Electronic Equipment, this can thus be considered as a complex business. The high number of heterogeneous elements involved in this specific waste business need to work in a connected way in order to succeed. Reference [5, p. 282] states that "steering sustainable development is problematic due to the ambivalence of goals, the uncertainty of knowledge about system dynamics, and the distributed power to shape system development". Reference [4] addresses the environmental problems, involved in systems with high degree of complexity and uncertainty. "These problems persist due to the diversity of actors involved (partly addressed through participatory approaches), the public goods nature and unclear dynamics of the natural resources and functions with which they interact, and the 'silo approach' in various realms of public policy that does not readily recognize these interactions"[4, p. 438].

It is important to emphasize that, "as much as this complexity is a problem, it is also an opportunity"[4, p. 438], when small behavioral changes may stimulate environmental transformation in a large scale. Those changes, as presented by [4],should be explored and linked with their triggers by environmental planning, providing alternative perspectives on how to deal with complexity and take advantage from it.

Uncertainty has been used with different meanings in a number of fields and has had different approaches by diverse authors throughout time. Although it has been studied for a long time, still today there seems to have no consensus on its definition, classification and operationalization. There is also a lack of understanding for the different dimensions of uncertainty and their characteristics, magnitude and means to deal with them. A broad definition of uncertainty is presented as "any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system"[6, p. 5].

Reference [7] states that considered to be one of the earliest attempts to define uncertainty is the perspective of Knight, separating the concept of uncertainty from risk in the dimension of degree of uncertainty. This approach states that it is possible to attribute a probability distribution of events for risk and that a riskmay be considered as a fake uncertainty. On the other hand, uncertainty has a higher degree of unawareness than risk and it is not possible to calculate possible future outcomes for an action, so that there is randomness with unknowable probabilities.

Reference [8] recognizes that entrepreneurs may benefit from uncertainties to produce economic value, when making decisions in uncertain contexts where other economic actors would not. Since Knight, uncertainty has been studied further by different areas of knowledge and with different approaches and has been seen as an important concern in entrepreneurship and business models [7].

There is a distinction in literature between objective uncertainty and perceived uncertainty. Supporters of the objective uncertainty argue that it is possible to objectively measure uncertainty and that it depends on the environment [9]. On the other hand, supporters of the perceptive view believe that an objective measurement is not possible, as it depends on the ways innovation is perceived by different actors [10]. This view states that uncertainty depends on the individual and defends that "building up interpretations about the environment is a basic requirement of individuals and organizations" (Daft and Weick, 1984, apud[7, p. 18]). Taking into account that the focus of the presented work is on the innovation behavior of the various actors involved in the context of high uncertainties of e-waste business, the perceived uncertainty view seems to be de most suitable to be analyzed further.

Reference [10] summarizes the inconsistencies and problems in the definition and measurement of environmental uncertainty. Perceived uncertainty is defined as "an individual's perceived inability to predict something accurately" [10, p. 136]. Therefore, actors perceive environments in different ways, which will be determinant to their behavior. Perceived uncertainty about the environment can be categorized into three types: state uncertainty or perceived environmental uncertainty; effect uncertainty; and response uncertainty.

The state uncertainty relates to the inability in predicting the future state of the organizational environment or a particular component of that environment. "Uncertainty about the state of the environment means that one does not understand how components of the environment might be changing" [10, p. 136], as for example uncertainty of what actions relevant organizations may take or uncertainty about nature of general changes in state.

The second uncertainty, effect uncertainty, is the inability of decision makers to predict how environmental events will impact their organizations. It depends, thus, on the conditions of the organization's external environment. "If state uncertainty involves uncertainty about the future state of the world, then effect uncertainty involves uncertainty about the implications of a given state of events in terms of its likely impact on the organization's ability to function in that future state" [10, p. 137].

Lastly, the response uncertainty concerns the inability of managers to identify available organizational actions and their outcomes, as to choose the best response to a specific change. "This type of uncertainty is experienced in the context of a need to make an immediate decision" [10, p. 138].

Table I – Sources of perceived uncertainty with respect to innovation decisions [12, p. 1224]

Sources of perceived uncertainty with respect to innovation decisions.

Uncertainty source	Description
Technological uncertainty	Uncertainty about the characteristics of the new technology (such as costs or performance), about the relation between the new technology and the technical infrastructure in which the technology is embedded (uncertainty to what extent adaptations to the infrastructure are needed), and about the possibility of choosing alternative (future) technological options.
Resource uncertainty	Uncertainty about the amount and availability of raw material, human and financial resources needed for the innovation, and uncertainty about how to organize the innovation process (e.g. in-house or external R&D, technology transfer, education of personnel). Resource uncertainty resides at the level of the individual firm, as well as at the level of the innovation system.
Competitive uncertainty	Uncertainty about the behavior of (potential or actual) competitors and the effects of this behavior.
Supplier uncertainty	Uncertainty about the actions of suppliers (i.e. uncertainty about the reliability of the supplier), whether the supplier will live up to agreements about the timing, quality, and price of the delivery. Supplier uncertainty becomes increasingly important when the dependence on a supplier is high.
Consumer uncertainty	Uncertainty about consumers' preferences with respect to the new technology, about the compatibility of the new technology with consumers' characteristics, and, in general, uncertainty about the long-term development of the demand over time.
Political uncertainty	Uncertainty about governmental behavior, regimes, and policies, ambiguity in interpretation of current policy or a lack of policy and unpredictability of governmental behavior.

It is interesting to highlight that although the innovation literature acknowledges the importance of uncertainty, the concept is still not well elaborated in studies concerning innovation. "While the course of technological change is widely accepted to be highly uncertain and unpredictable, little work has identified or studied the ultimate sources and causes of that uncertainty" [11, p. 117].

An interesting approach concerning the link between uncertainty and innovation decisions is the one presented by [9]. Based on an extensive literature review and previous empirical work, they propose a framework for perceived uncertainties involved in innovation decisions under socio-technological transformations. Considering the previous work of [10] about different sources of uncertainties and the importance of distinguishing them in order to choose the most appropriate strategies and taking into account different views from other authors,reference [9] focus on uncertainties present in organizational decision-making dealing with innovation projects.

References [9] – [12] present a framework with different sources of uncertainties, considering both the adoption and the development of innovations that are discussed in innovation studies and organizational management literature. The sources of uncertainties presented are: technological uncertainty; resource uncertainty (including uncertainty regarding labor and capital markets); competitive uncertainty; supplier uncertainty; consumer uncertainty (also known as market uncertainty); and political uncertainty (also called regulatory uncertainty or policy uncertainty). The description of each source of uncertainty is presented on Table I.

It is also important to consider the effects of uncertainties on innovation entrepreneurship actions. "Uncertainty is an important factor that can perpetuate damaging behavioral tendencies due to sunk-costs effects" [4, p. 441].

The presence of many uncertainties may be a major barrier to the breakthrough of new business and can retain the development and implementation of entrepreneurial activities [9]. Studying further the presence of uncertainties in a specific area of business is, therefore, an important step towards a better understanding of possible entrepreneurial activities.

III. METHODOLOGY

Taking into account the lack of further studies and the strong impact that uncertainties have in entrepreneurship, the presented study has the main goal of exploring the main uncertainties present on the recycling business of Waste Electrical and Electronic Equipment.

A systematic literature search has been conducted at the intersection of e-waste and uncertainty and the main uncertainties identified have been categorized according to the different types of uncertainty proposed by [5] – [9] – [12].

The search was conducted in the Web of Science website between 2014 August, 25th and 28th with the linkage between the words e-waste, WEEE, "waste electrical and electronic equipment" or "electronic waste"; and uncertainty, uncertainties or uncertain. The search resulted in 39 articles/papers, of which 22 have been excluded after analysis because they were not related to the subject. Therefore, 17 articles/papershave been further analyzed.

A. Technological uncertainty

Reference [13] argues that the relationship between information technologies and environmental sustainability is very uncertain and complex, with many specific problems of resource use, emissions and waste management. Reference [14] also states that there are difficulties in accounting the Waste Electrical and Electronic Equipment emissions during disassembly and disposal.

As electronics have many different elements in their composition, including a substantial fraction of the periodic table elements, they can be considered as one of the most complex waste streams. [15]

B. Resource uncertainty

As most of the forward production activities are not suited to deal with product movement the other way, reverse logistics costs are usually higher than the forward production system [16].

Reference [15] also states that, although it is possible to recycle up to 90% of the Waste Electrical and Electronic Equipment, the cost for this process is usually higher than the value of the recovered material.

C. Competitive uncertainty

The Waste Electrical and Electronic Equipment rapidly changing nature is very relevant, which results in difficulty of establishing an adequate waste treatment facility [15].

It is also important to mention the different recycling technologies existent [15], which try to follow the advances of different products that are put into the market. In order for the recycling facilities to be efficient and environmentally friendly, high investment and constant changesare needed.

D. Supplier uncertainty

Reference [16] states that the return flow of end-of-life electronics is not a demand-drive flow like in the forward production system, but a supply-driven flow, which has a very high level of uncertainty of return items concerning quantity, quality and timing. References [17] - [18] also mention those three aspects. Reference [19] talks about the uncertainty regarding the quality level of returned products as well.

References [15] – [20] also mention the uncertainty of collection rates. "Part of the uncertainty is caused by the fact that there is no information about the amount of old appliances stockpiled in households" [21, p.905].

The electronics' life span also represents an uncertainty. "Estimates are usually based on domestic demand for electronic devices and their average life span (i.e., the length of the time between the initial purchase of an electronic device and the time it completes its useful life). Life spans vary depending upon the type of device, economic and market conditions, age, and cultural behavior" [22, p.942]. Although there is a known increase rate of electronic use, reference [23] affirms that additional data are necessary to know the product residence times.

Reference [24, p.5] states that "studies on the age of e-waste returned for recycling have indicated that there is a wide distribution in the product lifespan". In this sense, it is very difficult to predict the amount and frequency of Waste Electrical and Electronic Equipment. Reference [25] also affirms that there is uncertainty of future supply and demand of recycled materials, mentioning the international markets.

Reference [26] affirms that there is a lack of knowledge about end-of-life electronics fate from individual and institutional users. Between the choices of dispositions, the authors mention the flow from intermediary sector to landfill, recycling and exportation. Reference [27] also mentions the uncertainty about the ultimate environmental fate of electronics.

E. Consumer/market uncertainty

Reference [28] mentions the different value of scrap materials on the secondary commodities market, affecting the recycling value of products.

Competition between the manufacturer and the remanufacturer is also present. In this sense, inter-firm relationship is very important to ensure stakeholders investments evaluation [29].

Further, "due to the inherent uncertainty and variability in product returns, no company can exclusively rely on filling the demand for new products from remanufactured ones" [19, p.1704].

F. Political/regulatory uncertainty

Reference [28] affirms that although legislators see the e-waste regulation as a very important to environmental thinking, the legislation is not uniform at the national and at the global level. Further, financial and collection schemes vary, with very complex regulations that sometimes are outdated.

"The disharmony between policies and procedures to regulate and manage e-waste can be linked to the differences in weights assigned to uncertainties in risk analysis among decision makers" [27, p.313].

IV. FINAL CONSIDERATIONS

Taking into consideration all the aspects mentioned during the literature review, table II summarizes the main aspects concerning uncertainties in the e-waste recycling business.

Table II – Summary of uncertainties in the recycling business of Waste Electrical and Electronic Equipment

Uncertainty Source	Description
Technological uncertainty	• Unknown environmental impacts; • Different product design and composition.
Resource uncertainty	• Unknown reverse logistics costs; • Variable cost of recycling.

Competitive uncertainty	• Rapidly changing nature of electrical and electronic equipment; • Different recycling technologies.
Supplier uncertainty	• Unpredictability about return of items concerning quantity, quality and timing; • Unknown destination flow of e-waste.
Consumer/ market uncertainty	• Different value of scrap materials; • Competition between the manufacturer and the remanufacturer.
Political/ regulatory uncertainty	• No common legislation at the national and global level; • Outdated political aspects; • Complexity of regulations.

During the literature review, it was evident that the recycling of Waste Electrical and Electronic Equipment faces many uncertainties and is involved on a very complex business. It involves not only the population, but also the companies and the government in many approaches. According to the authors' views, such approaches should be taken together by all actors involved to be effective.

Concerning future research, topics suggested are: to analyze how these uncertainties are managed by the different actors involved; or to study how is the accordance of views and projects among the different actors.

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