E-waste in Gaborone, Botswana – assessing the generation, handling practices, and strategies for improvement

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Abstract

E-waste includes components with economic and environmental importance, thus the need for their sound end-of-life management. This study provides fundamentals regarding the amounts, flows, and handling practices of e-waste in Gaborone, Botswana. A number of relevant stakeholder organisations were interviewed and an in situ waste composition study was conducted. The concentration of e-waste arriving at the municipal landfill is less than 1 weight per cent, corresponding to about 1.9 kg/capita/year, far less compared to the estimated 8 weight per cent for European Union countries. However, obsolete electr(on)ics are in urban storages primarily due to a lack of tapping mechanisms. Among several inadequacies of the current handling practices is the absence of an e-waste management framework. Improvement routes discussed include public sensitisation and engagement, capacity building, and future exploitation

of potentially suitable end-of-life treatment options including the novel phenomenon of enhanced landfill mining.

Key words: E-waste, Electrical and electronic equipment, Solid waste management, Resource recovery, Botswana

1. Introduction

Globally, the generation of waste electrical and electronic equipment (WEEE) has continuously increased and now constitutes 20 – 50 million tonnes per year (Ongondo et al., 2010). This increase is often attributed to the regular stream of new electr(on)ics on the market, their decreasing service lifetime, and consumer agitation to keep pace with such innovations (Ramzy et al., 2008). In many regions, such discarded products currently represent one of the fastest growing post-consumer waste streams, making up an increasing share of municipal solid waste (MSW) (UNEP, 2009).

Although the use of electr(on)ics in developing countries (DCs) is relatively low, many of these countries represent fast-growing economies and increasing amounts of WEEE are expected in the near future (Widmer et al., 2005). In addition, illegal dumping of WEEE in such countries adds to the annual amounts in need of handling. However, in most DCs there is no management system in place to handle these increasing WEEE amounts (Ramzy et al., 2008). Therefore, landfilling of WEEE together with other

MSW is widespread (Ongondo et al., 2010). This practice has resource and pollution implications and calls for the development of more sustainable management strategies (Chancerel & Rotter, 2009).

As the result of the above-mentioned conditions, research has increased its focus on WEEE management in DCs in Africa and Asia (e.g., Nnorom & Osibanjo, 2008; Manomaivibool, 2009; Wath et al., 2010). Most of these studies uncover the existing management practises and propose improvements based on lessons from industrial countries that have better management systems. The lack of management frameworks, recycling capacities, and landfilling are key challenges (Wath et al., 2010). Proposed improvements commonly revolve around abridged forms of the Extended Producer Responsibility (EPR) concept. However, these studies often lack quantitative data on the generation of different types of WEEE (Chancerel & Rotter, 2009) and accurate statistics on the amounts ending up in landfills is particularly scarce for many African countries (Ongondo et al., 2010), two fundamental characteristics needed for developing suitable waste management systems (Dahlén & Lagerkvist, 2008).

This study analyses the generation, composition, and handling of WEEE in Gaborone, the capital city of Botswana, to develop a foundation for priority-setting and to identify possible routes for improvement by considering both the physical flows and the socio-economic conditions in the city. In doing so, we address the following research questions:

- In what way does existing policy influence WEEE management in Gaborone and what are the current roles, perspectives, and interactions of key stakeholders?
- How much and what types of WEEE are annually generated from the socio-economic sectors in the city and which amounts of valuable and hazardous metals are related to these flows?
- Which features of WEEE management systems operating in industrial countries could be adaptable to the socio-economic conditions in Gaborone and which types of WEEE should be prioritized taking economic and environmental aspects into account?

1.1. Background

Botswana is a landlocked country in southern Africa with a population of 2,065,000 (CIA World Factbook, 2011). Gaborone, the capital city with a population of 218,000, has witnessed increased generation of solid waste due to rapid economic and population growth. Two government agencies are generally responsible for solid waste management in Gaborone. The Department of Waste Management and Pollution Control (DWMPC) outlines the regulations and the city council is responsible for waste collection from households and enforces the regulations for all non-household facilities.

In practise, all collected solid waste is transported directly to Gamodubu landfill, located about 35km from the city centre. In the case of WEEE, the city council encourages households to devise their own ‘‘safe’’ end-of-life handling due to lack of recycling facilities. The other socio-economic sectors in the city, such as industries and commercial sectors, have the responsibility to collect and dispose of their own solid waste, including WEEE. This disposal is often contracted to private waste collection companies for a fee. In addition, there is an active informal material recovery for glass bottles, steel cans, paper, plastics, and metal scrap from the city and landfill. These companies export the collected materials to South Africa and Zimbabwe for further processing. *Somarelang Tikologo* (Botswana Environmental Watch), an NGO in Gaborone, also educates locals on waste as a potential resource and operates a public drop-off centre for glass and plastic bottles and metal cans.

2. Method

The applied analytical approach can be divided into three parts: (1) uncovering the present WEEE handling practices; (2) characterizing the WEEE arriving at the municipal landfill; and (3) developing potential improvement strategies. Data collection was undertaken during a ten-week stay in Gaborone in the spring of 2011.

2.1. Analysing the WEEE management practice

Analysing WEEE management practices was mainly accomplished using face-to-face semi-structured interviews with key stakeholders (Table 1) in the waste management structure of Gaborone. These actors, all located in Gaborone, represented private collecting companies and recycling companies, governmental authorities, and non-governmental organizations. The interviews focused on the spatial and socio-economic distribution, handling practises, and existing policies. The personal household handling practises for e-waste was also discussed with each interviewee. In addition, field observations by the authors also provided insight into WEEE handling practises.

Table 1
List of stakeholders selected for interviews. The working position of the interviewed personnel representing each stakeholder organization is also presented as well as the reference numbers used in the text for citation of the interviewees.

Selected stakeholder	Job position of the interviewed personnel	Reference No
Department of Waste Management and Pollution control (DWMPC)	Executive of policy formulation section	1
Department of Environmental Affairs (DEA)	Desk officer for the Stockholm convention on persistent organic pollutants and UNCCD	2
Gaborone City Council	Head of the waste collection section	3
Collect-a-can	Gaborone regional manager	4
Simply Recycle	Manager and owner of the facility	5
Somarelang Tikologo (Botswana Environmental Watch)	Program officer	6
Computer Refurbishment Project (CRP)	Project manager	7
University of Botswana (UB)	ICT equipment maintenance department head	8

2.2. Sampling, quantification, and characterization of generated WEEE

The waste composition study was carried out at the Gamodubu landfill for eight consecutive days. Previous waste management studies in Gaborone indicate a stratified waste collection pattern from four strata – residential areas, commercial centres, industrial areas, and other sectors (e.g., institutions, national parks, and governmental offices). The waste sampling process was based on well-established standards. In this case, unprocessed municipal solid waste sampling methods described in ASTM D 5231-92 (American Society of Testing and Materials, 2003) and *RVF Utveckling* [Development] 2005:19 (*RVF - Svenska Renhållningsverksföreningen*, 2005) were used (Figure 1). Establishing a representative number of sorting samples relied on the theory of convergence. This theory implies that no more sampling need be done once the composition of the various waste components within the previously taken sorting samples are found to be consistent (Sharma & McBean, 2007). In practise, approximately 600 kg of waste were extracted and sorted from each of the four strata. Overall, eight vehicle loads of waste, two from each of the four identified socio-economic strata, were selected and analysed. From these mother samples, a total of 24 sorting samples were extracted and sorted. The WEEE obtained in this way was further divided into three secondary class electr(on)ic products – ICT and consumer electr(on)ics (printer units, telephone, audio amplifier, etc.); small household appliances (toaster, iron, scale, etc.); and lamps/lighting equipment (compact fluorescent lamp, low pressure sodium lamp, etc.) – based on the categorisation of such products in the EU WEEE directive (European Union, 2003).

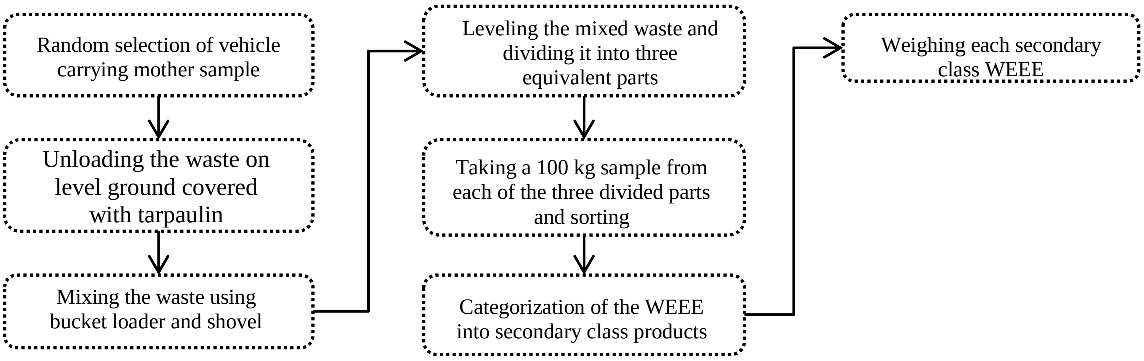

Figure 1. Flow chart of the subsequent activities related to the in situ waste composition study at the Gamodubu landfill. The figure describes the procedure for selection and analysis of each of the eight selected mother samples.

2.2.1. Assessment of Annually Landfilled WEEE and Related Metal Flows

To estimate the total amount of WEEE that is landfilled annually at the Gamodubu site, we combined the data from the waste composition study with a seven-day log of the quantities of solid waste arriving at the landfill from each socio-economic stratum. Furthermore, the annual flows of four metals related to these landfilled amounts of WEEE were calculated to indicate the inherent raw material value as well as potential hazardousness of these discarded products. Copper and aluminium were selected because of their extensive use in electr(on)ic equipment, and lead and mercury were chosen because of local pollution concerns. The content of these metals in the different secondary categories of WEEE was retrieved from the Swiss Federal Laboratories for Materials Science and Technology (EMPA, 2009).

2.3. Analysis of potential improvement strategies

State-of-the-art knowledge regarding management systems for solid waste and WEEE management in particular, obtained through a literature review, together with current WEEE handling practises was used to generate potential improvement strategies in Gaborone. However, to keep the strategies realistic, all proposed strategies were put in relation to the economic, infrastructure and organisational context of Gaborone. The assessed amounts and origin of WEEE that annually are deposited at the Gamodubu landfill and their related metal flows were also considered as a way to identify which types of WEEE should be prioritised when it comes to future recovery and pollution prevention initiatives.

3. Current management practice of WEEE in Gaborone

3.1. WEEE generation and collection

Electr(on)ic equipment is increasingly establishing a foothold in the socio-economic activities of Gaborone, which has resulted in increasing amounts of obsolete products (interviewee 1- 3, 7, 8). The generated WEEE originates from all the socio-economic strata in the city in varying amounts, type, and degree of dysfunction (Figure 2). So far, however, there is no structured framework to address the increasing flows of these obsolete products with the exception of some sporadic attempts by a handful of companies, government offices, and individuals to manage their own WEEE (1- 3, 7).

The administration of “proper” (EoL) collection is largely left to the individual waste generator (1, 3). Unlike other kinds of solid waste, the city council’s responsibility is currently only to ensure provision of “proper” EoL treatment for WEEE, which in practice means landfilling. A number of private companies also provide solid waste (including WEEE) collection for a fee (3). Private waste companies (including scavengers) and NGOs, however, are primarily interested in recovering plastics, bottles, and metals for which there is an existing market (3, 4 - 6). This limitation is also the result of a lack of technical capability and business satisfaction with the current line of operation (4, 5). Furthermore, individual and community level awareness of WEEE both as a hazard and potential resource is generally low (1- 8). Individuals are instead particularly interested in the functionality prospects of the devices. Thus, the most common disposal route of WEEE is to throw it in the MSW bins destined for landfills (1 - 8). However, corporate-level consumers and governmental organizations have relatively better level of awareness of the hazards of treating WEEE as MSW (1 - 3, 7, 8).

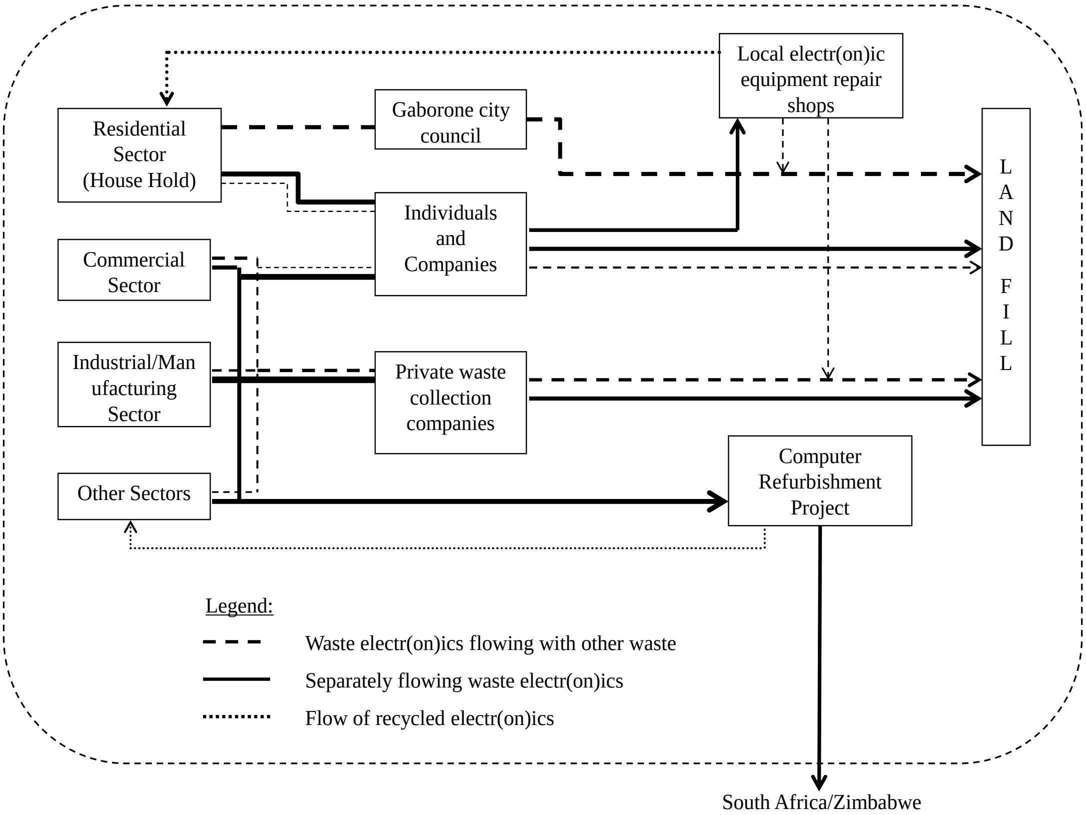

Figure 2. Schematic illustration of the various flows related to faulty or obsolete electr(on)ic products in Gaborone, Botswana.

3.2. Treatment of faulty and obsolete WEEE

The only formally organised recovery initiative for WEEE is the Computer Refurbishment Project (CRP), initiated by the government to reclaim and restore obsolete ICT equipment from governmental offices, private companies, and households (1, 7). So far, more than 12,000 ICT computers and printers have been collected from governmental offices and approximately 2,000 computers have been repaired and supplied to 200 primary schools throughout the country (7). The remaining products in storage are beyond repair due to severe damage, lack of expertise, and financial resources (7). Previously, most corporate and governmental offices sold their WEEE to recyclers in South Africa and Zimbabwe (1, 7, 8). This recovery route, however, is becoming less available due to the introduction of the CRP and in some cases standardized environmental management systems (EMS) (8). Standardized EMS mean that companies apply better maintenance and upkeep programs and auction off electr(on)ic equipment to be reused by employees or the general public before considering other forms of treatment.

There are also plenty of informal places in the city involving people who recover and repair faulty electr(on)ic equipment (1, 7). Swapping damaged parts of electr(on)ic equipment for new, or at least functional, parts is a common technique of restoration used in these repair shops.

Individual households are often reluctant to dispose of faulty electr(on)ic products due to the perceived residual value (1- 8). Hence, the equipment often stays in the hands of their owners despite being obsolete, with the hope of future repair or finding another type of use(r) for the “valuable” product (1- 8).

4. Composition study at the Gamodubu landfill

4.1. Amount and composition of WEEE in the landfilled solid waste

Results from the waste composition study indicate that the solid waste originating from the industrial sector has the highest concentration of WEEE (Table 2). However, the concentration of WEEE in the analysed solid waste is generally low – less than 1 weight per cent (wt%) – regardless of its socio-economic origin. It is noteworthy that the occurrence of WEEE in solid waste originating from other sectors (e.g., governmental offices, banks, schools, and the like) is an order of magnitude lower than in waste from the other socio-economic sectors. This difference could partly be explained because corporate-level consumers are more aware of the hazards of treating WEEE as general garbage among.) In addition, such organizations mostly purchase and operate new electr(on)ic equipment and apply routine maintenance to improve continually the equipment's performance, strategies that also reduce outflow of WEEE (1- 3, 7, 8).

If the total amount of WEEE that annually is landfilled is emphasized, almost 70 wt% originates from households. From this perspective, solid waste from the commercial sector also contributes significantly to the amount of landfilled WEEE, whereas the annual flows of discarded electr(on)ic products from industries and other institutions appear more or less negligible.

Table 2
Summary of results for the waste composition study at Gamodubu landfill, rounded numbers. The amount and composition of WEEE in the solid waste arriving to the landfill is divided into the different socio-economic strata of the city. An estimation of the total amount of WEEE that is annually landfilled at Gamodubu is also presented.

Socio-economic origin of mother sample	**Total weight of sorting samples (kg)**	**Total amount of WEEE in sorting samples (kg)**	**WEEE divided on secondary categories** (wt%)			**Landfilled amount of solid waste (tonnes/y)**	**Landfilled amount of WEEEE (tonnes/y)**
			ICT & Consumer electronics	Small household appliances	Lamps		
Household waste	600	5	30	50	20	35,700	300
Commercial waste	610	4	90	10	0	18,800	120
Industrial waste	570	6	50	50	0	1,400	10
Other waste	570	0	0	0	0	6,900	0
		Total estimated quantity of WEEE disposed at the landfill annually (tonnes)					430

In total, it is estimated that approximately 430 tonnes of WEEE is annually landfilled at the Gamodubu site, which corresponds to 1.9 kg/capita/year. Almost 50 wt% of this amount is ICT equipment, 40 wt% is small household appliances, and the remainder is varying types of lamps. For ICT equipment, solid waste from both the commercial sector and households is an important source, while the annual flows of small household appliances and lamps to the landfill are more or less solely related to the disposal of household waste.

The landfilled amounts of WEEE are related to both valuable and hazardous substance flows (Table 3). Approximately 80 wt% of the copper, 50 wt% of the aluminium, and 60 wt% of the lead that annually ends up in the landfill is related to landfilling of small household appliances, making this category of WEEE a top priority for both resource recovery and pollution prevention measures. For mercury, lamps are the only type of WEEE that need be considered because of their comparatively higher mercury content.

Table 3
Average content (in wt%) of copper, aluminium, lead, and mercury in the three secondary categories of WEEE separated during the waste composition study at the Gamodubu landfill. The estimated annual flows of these four metals related to the landfilling of WEEE are also presented, rounded numbers.

Secondary WEEE category	**Metal content in the separated secondary categories of WEEE** (wt%)[a]				Estimated **annual amounts of metal in the landfilled WEEE at the Gamodubu landfill (tonnes/y)[b]**			
	Copper	Aluminium	Lead	Mercury	Copper	Aluminium	Lead	Mercury
Lamps	< 1	14	< 1	< 1	< 0.001	6	< 0.001	< 0.001
ICT and consumer electronics	4	5	< 1	< 1	8	10	1	< 0.001
Small household appliances	17	9	1	< 1	29	16	1	< 0.001

[a]Based on data reported by the Swiss Federal Laboratories for Material Science and Technology (EMPA, 2009)
[b]Obtained by multiplying the metal content of the secondary WEEE categories with the annual flows of these categories to the Gamodubu landfill, presented in Table 2.

5. Concluding discussion – possible routes for improvement

Our findings indicate a variety of challenges and strengths of WEEE management in Gaborone. Now that these challenges and strengths have been identified, we can turn to a discussion about possible routes for improvement. Emphasis is on short-term measures but some more sophisticated, long-term strategies are also discussed. This analysis revolves around three largely related issues: (i) how to minimize current WEEE flows for disposal; (ii) how to facilitate development of separate WEEE collection systems; and (iii) which treatment options could be developed for the collected WEEE in the long-term.

5.1. Minimizing current WEEE flows for disposal

A frank measure to significantly reduce flows to the landfill would be to expand the governmental CRP by also attracting obsolete ICT from households and commercial sectors. However, these sectors represent much larger flows of WEEE in general and obsolete ICT in particular, implying a need for additional financial resources to cope with higher costs for, e.g. staff and temporary storage. A potential way for the government to facilitate such a measure could be to support and integrate the informal repair and refurbishment expertise and activities in the city as part of the CRP. This would presumably offer new jobs, enhance the ability to repair such faulty products for new markets, and alleviate the perceived tension between formal and informal WEEE recycling activities (Manomaivibool, 2009).

Our findings also indicate that there are substantial amounts of WEEE accumulated in the city. Similar findings have been reported in other developing (Nnorom et al., 2009) as well as industrial countries (Kapur & Graedel, 2006; Milovantseva & Saphores, 2012). Such so-called material hibernation delays the outflow of WEEE, which in this case saves landfill space and limits environmental impacts related to landfilling (cf. Milovantseva & Saphores, 2012). In addition, indoor storage of WEEE preserves the material quality and offers buffer time for implementing better management systems. When a recycling system is in place, owners of these hibernating material stocks will more likely make these stocks available for the recycling stream. Information campaigns and other incentives could help encourage the owners of these stocks to use this option.

5.2. Critical conditions for development of separate WEEE collection

Functional waste collection systems rely on conditions such as accessibility, ability for guidance and control, infrastructure, and motivation among users (Krook & Eklund, 2010). A public awareness campaign on resource and pollution implications of WEEE disposal could serve as a start. Given that earlier pilot programs on source separation have failed due to a lack of curb-side collection (a program that needs city council support), drop-off sites seem a more viable option. This strategy could perhaps be initiated by the Botswana Environmental Watch. In addition, CRP could expand their current sites so they could also accept WEEE from households and commercial sectors. Another way to use existing sites and structures, which the people of Gaborone are aware of and are accustomed to, is again to incorporate repair shops into such a collection system. Over time, new drop-off sites for WEEE, and perhaps also other types of waste, could then gradually be developed in areas where people frequently visit, such as shopping malls, bus stops, and dwelling blocks.

5.3. Potential treatment options for collected WEEE

In the end, a collection system needs to find suitable treatment options and markets for the sorted waste (Petersen, 2004). For Gaborone, three options are anticipated, ranging from low to high investment costs. Enhanced landfill mining does not see the landfill as a final deposit but as a temporary storage place for secondary resources awaiting recovery (Passel et al., 2012). Storage structures to keep the separated WEEE in good condition and with enough capacity for present and future flows would have to be constructed. This strategy would offer the opportunity to select the most suitable time to recycle the WEEE depending on, for instance, the state of available technology and economic feasibility. However, a critical challenge of such an approach is that until such “favourable” conditions occur, it will only generate additional costs for waste management. Here, public-private partnerships might offer a solution, where companies and investors see this increasing pile of WEEE as a potential business opportunity.

Another plausible treatment option is to export the separated WEEE to countries with an existing recycling industry. However, large-scale export of WEEE will face the scrutiny of the Basel Convention (UN, 2005), which prohibits the trans-boundary movement of hazardous goods. Again, the viability is largely reliant on economic dimensions in general and what type of transnational agreements can be developed between Botswana and other countries – a complex political issue far beyond the scope of this study.

Developing a domestic recycling industry probably represents the highest potential for creating new jobs and keeping the valuable parts of the WEEE within the region. However, such an industry will essentially require developing a standardized WEEE management framework, building recycling facilities, and presumably collecting larger amounts of WEEE to take advantage of economy of scale (Ayres et al., 1997; Wath et al., 2010). The latter condition will plausibly occur sooner or later given the economic development in the country and could be further facilitated by initiating the concept of Enhanced landfill mining. A more critical challenge is the lax enforcement of waste management regulation in Gaborone and lack of collaboration among different societal actors, which could render any attempt to develop a management framework redundant.

The authorities in Gaborone now need to investigate which options they find most suitable given their ambition and available resources. In this work, it might be fruitful to consult experts from other countries who already have a functioning management system for WEEE and learn from their experiences and mistakes. Through this study, we have provided some fundamental data regarding the physical quantities, flows, and handling practices of WEEE in the region. We hope this approach has established a foundation from which this challenging endeavour can be further developed.

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