PLATE
Product Lifetimes And The Environment

Quantifying the conservation value of independent, place-based repair: a case study of an electronics repair cluster in Lima, Peru

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Abstract: Repair and maintenance of consumer electronics can conserve the materials and energy they embody. Independent or third-party businesses are important sites of such repair and maintenance activity. While the value of such businesses is sometimes captured in official socioeconomic statistics (e.g., employment; tax revenues; contribution to GDP), little attention has been paid to their role in the conservation of resources. In this paper we examine the conservation value of a cluster of independent third-party electronics repair businesses in Lima, Peru. Using life cycle assessment (LCA) of phones and tablets we quantify the conservation value of this cluster in terms of CO_2 equivalent (CO_2e) and water consumption relative to new manufactures of the same categories of electronics. We then discuss the politics of attributing the conservation value achieved by the third-party repair cluster in Lima to either domestic (that is, Peruvian) or foreign CO_2e . Whose conservation of CO_2e is this? How do the answers to that question shape understandings of the relevance of location for industrial ecology? Our work contributes to the broader field of spatially explicit LCAs and their incorporation into the emerging subfield of political industrial ecology.

Introduction

Normative concerns are at industrial ecology's core. As Zhu writes, IE seeks to "generate and use research findings to support decision-making and social change" (2020, p. 1). Researchers from outside the field of IE proper have recently articulated what they see as a need for more substantive and explicit linking of IE research and 'the political' — broadly defined as struggles pertaining to power and how they shape the situations in which industrial projects or stocks and flows of resources are situated (Breetz, 2017; Newell et al., 2017). These research concerns with the political lead advocates to articulate the case for political industrial ecology or PIE.

PIE research typically involves collaborations between researchers across physical sciences, engineering, and social sciences. This is the situation with our paper in which a cultural geographer and three engineers are working together on questions about the environmental, social, and economic significance of electronics maintenance and repair by small, independent businesses in a variety of case study locations. Our work seeks to map the spatial organization of supply chains and customer networks of these businesses; determine their economic contributions to the places they locate (e.g., via employment and wages); discern how such businesses adapt to technological change (e.g., the ongoing transition away from cathode-ray tube to flat screen monitors); and to evaluate the conservation value of the work performed at these businesses in terms of energy and material conservation, and waste mitigation. This paper confines its analysis to measuring the energy and material conservation value of the work performed at these businesses dedicated to the maintenance and repair of consumer electronics devices in the case of Lima, Peru.

The Case: Lima, Peru

Collaborative fieldwork began in Lima in 2014 to gather data on independent electronics maintenance and repair businesses in the city. Data collected included location (i.e., address or street location) and types of devices maintained or repaired (e.g., phones, computers, displays). The fieldwork also included in-depth, semi-structured interviews with the proprietors of these businesses (often sole proprietorships) and, in some instances, employees of multi-person operations. The interview data are beyond the scope of this paper.

Despite the substantial number of such businesses operating in Lima and its surrounds, their relatively small size coupled with a propensity to operate outside of formal statistical categories gathered by the state means that on the ground fieldwork to collect location data has been necessary. We identified approximately 2,080 individual repair businesses comprising 11 clusters of businesses in Lima (Figure 1). Our fieldwork also found that while individual businesses in the sector often specialize in maintaining and repairing one or just a few related classes of devices, in the aggregate a very wide range of electronics are handled by the sector. Among these businesses one can find maintenance and repair services for everything from consumer electronics like desktops, laptops, mobile phones, and tablets to televisions (CRT and flat screen), routers, peripherals (e.g., printers, keyboards), audio equipment, lighting, domestic appliances (e.g., washing machines and refrigerators), domestic solar panels, and more. We confine our analysis in this paper to smartphones and tablets as indicators of the conservation value of this sector.

Methods

Life cycle assessment (LCA) is the main methodology used in this paper. LCA incorporates the different stages in the life cycle of a product (e.g., from raw materials extraction to the end of life management of the product) with the aim of calculating the environmental impacts of a product. As discussed below, our LCA also includes spatially explicit information such as origin of device manufacture, distance to point of import to Peru, and typical device types maintained and repaired in Lima.

Each stage of an LCA requires an inventory that includes materials, energy, transportation and other relevant information to understand, for example, how a product was manufactured, distributed or used. To properly address all desired objectives of an LCA it is extremely important to define the system boundaries (International Organization for Standardization, 2006). The boundaries of our system are shown in Figure 2.

The LCA performed in this study has the main purpose of evaluating the environmental contributions of electronic repair and maintenance in Peru with regards to the reduction of greenhouse gas emissions and water consumption. To assess those contributions, we worked towards two main goals related to the life cycle inventory. Whereas the first goal relates to the comprehension of the components, transport and electricity that represent an average smartphone and tablet in Peru, the second one is related with tools, machines, equipment, and electricity used to repair by replacing components in the devices selected, and it is important to note LCA was performed to an 'average device', that relates to the model that was selected and based on the most common device imported to the country in 2018.

The functional unit for this study is the electronic device, (e.g., tablet or smartphone), used by an individual, without any repair, maintenance or component replacement, over a 5 year lifespan. Moreover, different scenarios are compared to this initial analysis. The first scenario assumes that a user will possess different devices, i.e., two smartphones, in the analyzed period. The second scenario includes the life cycle extension of the device assuming different repair, maintenance and replacement practices within the 5 year lifespan. Devices considered in the analysis are new and manufactured in China. In the study, we assume that M&R activities aimed at extending device lifespan, requires a change in some components of devices. It is assumed spare parts used for maintenance and repair (M&R) activities are easily found in the local market. Since repair is done in place, locally in Lima rather than requiring transport outside the country to complete repairs, international transportation was omitted from our calculations of global warming potential (GWP) and water. Also, the weight of the components and their respective sizes, assumed for both devices in this study, are consistent with the bill of materials of other similar devices (Babbitt et al., 2020).

Modeled scenarios are based on typical M&R practices gleaned from technicians interviewed in Lima. We also consulted online sources of M&R activity such as iFixit and Youtube, both of which offer hundreds of video tutorials worldwide that guide technicians or even amateur repairers to solve common issues with their devices. Since the scenarios we modeled are common beyond Lima, the results we report are likely to be applicable to M&R activities in other localities within and beyond Peru.

Selection of representative devices

Selection of the smartphone or tablet to be analyzed was based on the Peruvian government's database of imports and exports (SUNAT, 2018) and experience from fieldwork at M&R clusters in Lima. Based on this information, an average imported smartphone and tablet for the year 2018, was selected. To build our inventory, different sources were used, as seen in Table 1, and then data collected were extrapolated to other dimensions to obtain a representation of the 'average device'.

Also, the transportation and use phases of the 'average device' were modelled. Calculations of transportation were based on the distance between the origin of the device and its destination of import. In this study Shenzhen, China, was considered as the place where devices were assembled, and the final destination is Callao Port, Peru. An intermediate calculation based on imports to Peru that considers midway ports, and an average total of ton-kilometer (tkm) calculated based on data from the Peruvian customs authority (SUNAT, 2018).

Moreover, there is broad evidence that an average user keeps a smartphone between 2-3 years (Belkhir & Elmeligi, 2018). However, there is a trend in which the average lifespan of smartphones is growing to more than 3 years of use (O'Dea & Statista, 2020). Also, there are studies that mention that the lifespan of a smartphone could be 5 years or more, depending on the user (Makov et al., 2019). In addition, there is evidence in Peru that many people have access to different M&R clusters, such as the main cluster in downtown Lima (Gusukuma et al., 2017). Our baseline and additional scenarios fit within this range of lifespans reported in this literature.

In the case of tablets, some studies consider that they could have between 3 to 8 years of lifespan (Belkhir & Elmeligi, 2018). Nevertheless, recent LCA studies of tablets consider 3 years of lifespan (Clément et al., 2020; Hischier et al., 2014). The assumed tablet lifespan was 3 years with the possibility to extend it to 5 years by repairing it.

Defining repair and maintenance scenarios

The main M&R procedures modelled in this study are defined based on a combination of interviews with repair technicians in Lima and an extensive search performed on the Youtube and iFixit platforms. Interviewees indicated they have a mix of formal and informal training in electronics repair. Some are self-taught or trained in apprentice-style relationships. Others learned their skills as technicians trained by original equipment manufacturers, but who later left those enterprises to work as independent, self-employed technicians. Interviewees helped us define common repair and maintenance scenarios. We corroborated these scenarios by consulting iFixit's repair manuals (Raihanian Mashhadi et al., 2016) and, in the case of Youtube, we used a tool created by the Digital Methods Initiative (DMI) to systematically query the platform for repair related search terms (Rieder, 2015). Data retrieved from Youtube related to different possible repairs and replacements in smartphones and tablets. The search included videos uploaded between 2000 and 2019. The keywords used in the search process were in English and Spanish, such as "Battery replacement / *Reemplazo de Bateria*", "Display replacement / *Reemplazo de pantalla*". The main objective of the search was to capture a general trend of searches, views and likes along the analyzed time period to help us define common repair scenarios. Also, search results were filtered to identify relevant data related to smartphones and tablets. This search showed an important increase of video tutorials related to M&R between 2010 and 2019. Also, a significant number of videos were associated with the replacement of displays, speakers, batteries, cameras, and small vibration motors. After searching data from Youtube, the 'average model' was compared it with the M&R tutorials of similar models on the iFixit webpage. In the case of smartphones, iFixit's website offers detailed tutorials for repairing different models and their related components. In the case of tablets, it was more challenging to compare repair procedures between models because there were fewer updated video tutorials on the web page. The final selection of M&R elements, as shown in Table 2, was based on both sources: Youtube videos and iFixit manuals.

Four scenarios were modeled considering a five-year lifespan (Figure 3). The first scenario, A, assumes no M&R activities for the five years. Scenario B assumes no M&R activities during the first three years and the replacement of the equipment with a new one after year 3. Then, Scenario C, assumes that the user repairs a component in the third year as well as a battery replacement. Many studies pointed out that a battery lasts 3 years, so we assume that every three years this component needs to be replaced. Finally, Scenario D assumes two M&R processes plus two battery replacements.

Results

Figure 4 shows the normalized results of M&R processes when compared to buying a new device, for both impact categories: Global warming potential (GWP) and Water consumption (WC).

As observed in Figure 4, M&R activities that generate the highest impacts are the ones related to the replacement of the display, front camera, and rear camera.

Results from the modelled scenarios are shown in Table 3 and 4. Table 3, shows a comparison between Scenario A and B in which the only stages considered were components to manufacture the devices, transportation, and energy of their use phase. Moreover, Table 4, considers a comparison of the average device with different M&R procedures, all of which include changes of battery, one change in the scenario C and two changes in scenario D. It is noted M&R practices for a smartphone could be always more beneficial than buying a new phone, in the same manner regarding M&R practices related to tablets. One exception, however, is found when replacing the display more than once, a practice we calculate to be comparable in terms of environmental impacts to buying a new tablet.

Our results show that M&R activities represent substantial savings in terms of GWP and water consumption relative to the purchase of new devices (Figure 4). However, not all repair combinations are equal and some combinations have higher conservation values than others. For example, Scenario D for tablets in which the display and battery (D + B) combination are repaired twice over a five year lifespan results in a GWP of 110 CO_2e versus 122 CO_2e for Scenario B for tablets (new purchase, followed by replacement new purchase at Year 3). These results suggest that while M&R activities are important in terms of conservation they cannot fully overcome the energy and material consequences of decisions made in the design of devices.

Discussion and Conclusion

With over 2,000 independent electronics M&R businesses operating in Lima, the aggregate conservation value of the work performed at these establishments is substantial. Yet, that value remains under appreciated and disconnected from measurements of impacts associated with electronics design and manufacturing. Our research on maintenance and repair of electronic devices suggests a need to consider the conservation value of activities that may not be spatially co-present with manufacturing yet which nevertheless have important role in the conservation of energy and materials.

In the case of Lima, Peru M&R of devices are at a distance from sites of both design and manufacture of those devices. M&R happens where use of devices does. This spatial arrangement raises questions about how the energy and material conservation of M&R is attributed within the system boundaries. There is no non-arbitrary way to define whose conservation (e.g., in terms of CO_2e and water) M&R pertains to, but nor are the answers to that question neutral.

Manufacturing is the most impactful stage of device life for phones and tablets (Glöser-Chahoud et al., 2021). Yet, if the conservation value of M&R is attributed to design or manufacturing, then system actors with the most power to effect changes to devices that would reduce their material and energy impacts are gifted with a savings value provided by actors in much more vulnerable economic positions who have no power to affect upstream changes in design or manufacturing.

Alternatively, if the conservation of M&R is attributed to the use phase of devices, then these material and energy savings could be accrued to national carbon and water accounts. In this case, actors affecting M&R might receive greater appreciation for their role in national level conservation efforts.

The different possibilities for attributing the conservation value of M&R in LCA analyses also point toward different, albeit not inherently mutually exclusive, policy-making outcomes for decision-makers. For example, attributing the conservation value of M&R to manufacturing might attenuate attempts to mandate designers and manufacturers to create devices with lower environmental impacts in favor of voluntary action on the part of producers. On the other hand, attributing the conservation to the use phase of devices may point to national and subnational policy-making that could benefit the M&R sector. Examples could include right-to-repair legislation, which is gaining ground in the European Union and elsewhere, and subnational, even municipal scale, policies such as tax reforms (e.g., reducing sales and/or value-added taxes) for the M&R sector as is happening at the national level in Sweden (Starritt, 2016) and at the municipal level in Graz, Austria (Piringer & Schanda, 2020).

The various policy scenarios briefly outlined above point to the importance of incorporating spatial information into LCAs. The importance of incorporating such information has been long recognized (Reap et al., 2008a, 2008b). However, a PIE approach brings politics (i.e., struggles pertaining to power) into industrial ecology analyses with LCA components that might more traditionally focus on quantifying stocks and flows (e.g., of materials and/or energy). We have shown how a PIE approach to LCA (and IE more broadly) can offer constructive pointers to how the field might address policies impacting the conservation value of electronics maintenance and repair in their international, national, and local relations.

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Figures and Tables

Figure 1. Locations and counts of electronics maintenance and repair businesses in Lima, Peru.

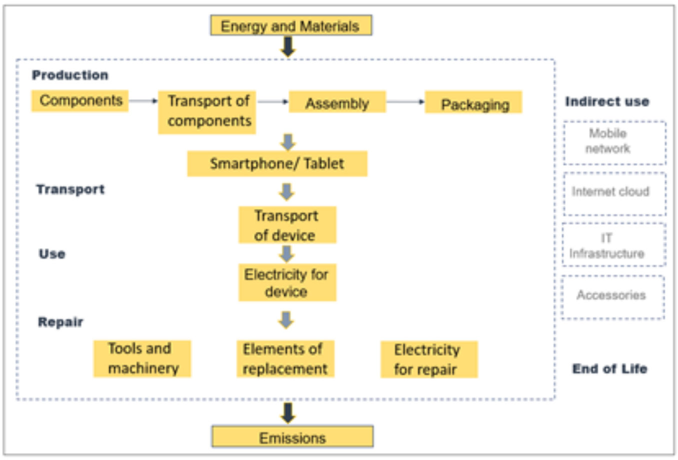

Figure 2. Smartphone and tablet boundaries.

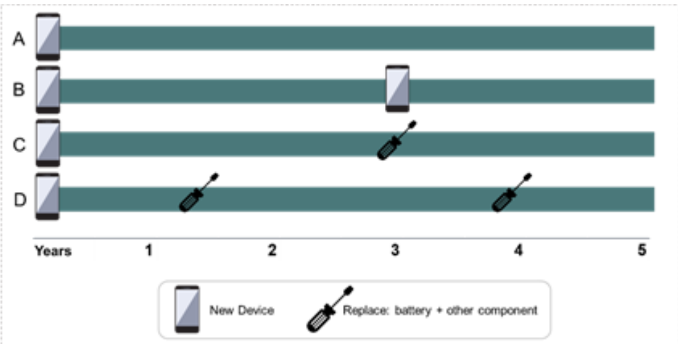

Figure 3. Repair scenarios over five-year lifespan.

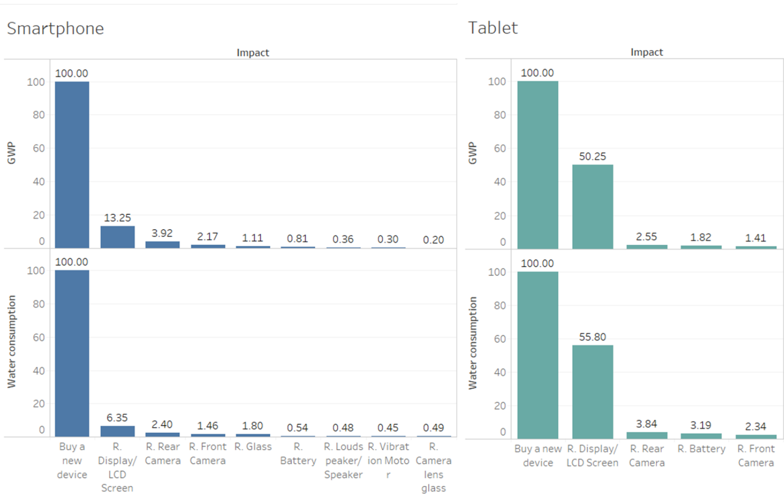

Figure 4. Main repair processes normalized relative to purchase of new device (100).

Table 1. Sources used to build the bill of components of average devices.

Element	Smartphone	Tablet
Batteries	Weight: Güvendik (2014)	Teehan & Kandiklar (2013)
Cable	Model of entire element: Andrae et al. (2014)	Model of entire element: Andrae et al. (2014)
Electro-mechanics	Güvendik (2014), Teehan & Kandiklar (2013)	Güvendik (2014), Teehan & Kandiklar (2013)
Integrated circuits (IC)	Proske et al. (2016), Teehan (2014)	Güvendik (2014), Teehan & Kandiklar (2013)
Mechanics / Materials	Güvendik (2014)	Güvendik (2014), Teehan & Kandiklar (2013)
Display	Güvendik (2014)	Güvendik (2014), Teehan & Kandiklar (2013)
PCB	Chipworks (2020)	Teehan & Kandiklar (2013)
Other PCBA components	Güvendik (2014)	Güvendik (2014), Teehan & Kandiklar (2013)
Black box modules	Güvendik (2014), Proske et al. (2016)	Güvendik (2014), Proske et al. (2016)
Transport of specific components (Pre-assembly)	Güvendik (2014)	Güvendik (2014),

Table 2. Components repaired (R) according to device.

Component to replace	Smartphone	Tablet
Battery	R	R
Glass	R	
Display/LCD Screen	R	R
Front Camera	R	R
Rear Camera	R	R
Loudspeaker/ Speaker	R	
Vibration Motor	R	
Camera lens glass	R	

Table 3. Comparing Scenario A (1 new device purchase over 5 years) versus Scenario B (2 new device purchases over 5 years).

Element	Impact categories	Unit	Smartphone	Tablet
Scenario A	GWP	kg CO_2 e	38.8	61.1
	Water consumption	m^3	0.6	1.0
Scenario B	GWP	kg CO_2 e	77.7	122.3
	Water consumption	m^3	1.2	2.0

Table 4. Scenarios C and D. B: Battery, G: Glass, D: Display/LCD screen, FC: Front camera, RC: Rear camera, L: Loudspeaker/Speaker, VM: Vibration Motor, CG: Camera Glass.

			Smartphone							Tablet		
Element	**Impact categories**	**Unit**	**G + B**	**D + B**	**FC + B**	**RC + B**	**L + B**	**VM + B**	**CG + B**	**D + B**	**FC + B**	**RC + B**
Scenario C	GWP	kg CO_2 e	39.4	43.17	39.8	40.3	39.2	39.2	39.2	85.8	62.66	63.2
	Water consumption	m^3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.2	1.00	1.0
Element	**Impact categories**	**Unit**	**2(G + B)**	**2(D + B)**	**2(FC + B)**	**(RC + B)**	**2(L + B)**	**2(VM + B)**	**2(CG + B)**	**2(D + B)**	**2(FC + B)**	**2(RC + B)**
Scenario D	GWP	kg CO_2 e	40.0	47.5	40.67	41.8	39.6	39.5	39.5	110.5	64.2	65.3
	Water consumption	m^3	0.6	0.7	0.62	0.6	0.6	0.6	0.6	1.4	1.0	1.0