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Lifetime extension of mobile Internet-enabled devices: Measures, challenges and environmental implications

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Abstract: Increasing the service lifetime of mobile Internet-enabled devices (MIEDs) such as smartphones, tablets and laptops is a promising strategy to reduce the number of devices that need to be produced and reduce environmental impacts associated with device production. A broad spectrum of lifetime-extending measures has been explored in literature and in industry practice. In this article, we present an overview of explored measures, discuss challenges in their implementation and environmental impacts of lifetime extension. We find that measures can be distinguished into measures aiming at (1) the improvement of the device design (e.g. modular or durable design of smartphones), (2) device retention (increasing the time a user keeps a device, e.g. by offering repair services or fostering emotional attachment to devices), and (3) recirculation (creating a second life with a different user and/or in a different context, e.g. by refurbishing and reselling devices). The implementation of measures is challenged by trade-offs faced by organizations in the MIED value chain, which specifically occur when revenues depend on the number of new devices produced and sold. Furthermore, measures are subject to rebound and induction effects (e.g. imperfect substitution, re-spending effects), which can compensate for the (theoretical) environmental gains from service lifetime extension. In particular, it is uncertain to what extent a measure actually leads to lifetime extension and eventually reduces primary production of devices (displacement rate). Thus, more systematic research is needed on the feasibility of measures and the conditions under which they effectively contribute to a net reduction of environmental impacts.

Introduction and approach

Mobile Internet-enabled devices (MIEDs), such as smartphones, tablets or laptops require a large amount of resources and energy during production (Hilty & Bieser, 2017). Estimations of the greenhouse gas (GHG) emissions caused by the information and communication technology (ICT) sector worldwide range from 1.5% to 4% of global GHG emissions, most of which are caused by the production and operation of end user devices (Bieser et al., 2020) with the main share in production (Bieser & Coroamă, 2020; Itten et al., 2020).

At the same time, the average service lifetime of a MIED is much shorter than the technically feasible lifetime (Thiébaud (-Müller) et al., 2018). For example, in Switzerland a mobile phone is used on average for roughly 3.3 years (Thiébaud (-Müller) et al., 2018). Thus, a promising strategy to reduce the environmental footprint caused by MIEDs is to increase their average service lifetime, with the aim of reducing the number of units produced.

Several measures to extend the service lifetime of MIEDs have been explored in literature and industry practice. For example, André, Söderman and Nordelöf (2019) discuss commercial reuse operation for laptops, Schischke et al. (2016) discuss modular smartphone design, Xun Li et al. (2010) and Zink et al. (2014) suggest reusing obsolete equipment in a different context, e.g. for educational purposes at schools or as in-car parking meters.

In this article, we provide an overview of measures to extend the service lifetime of MIEDs that have been explored in literature and cluster the identified measures into categories by their basic mode of action. We discuss challenges in the implementation of measures, as well as environmental consequences associated with measures (e.g. rebound effects).

Even though we reviewed a vast amount of literature, we do not claim that the resulting list of measures is exhaustive.

Measures to extend the service lifetime of MIEDs

Overview

In total, we identified three categories of measures:

1. *Improve device design*: improving technical features of devices to increase the service lifetime
2. *Retention*: increasing the time a user keeps a device
3. *Recirculation*: encouraging use of device by an additional user and/or in a different context

Table 1 provides an overview of measures in each category, which are described in more detail in the following.

Category	Measure
Improve device design	Avoid software-induced obsolescence
	Avoid hardware-induced obsolescence
	Software-induced behavior change
	Improve reparability and upgradability
	Design for durability
	Increase user attachment to device
	Design for reuse of components
Retention	Provide possibilities to repair device
	Increase user attachment to device
	Increase awareness for environmental impact of device production
Recirculation	Resell device
	Pass on device
	Device-as-a-service
	Repurpose device in different context
	Retrieve still functioning parts/devices for reuse

Table 1. Measures to extend the service lifetime of MIEDs clustered into categories.

Improve device design

Measures in this category aim at changes to the hardware or software design of MIEDs which (can) lead to an extension of their service lifetime by creating conditions that are beneficial for retention or recirculation.

Most measures require manufacturers to systematically take design choices (e.g. allow for replacement of battery) or abolish existing practices to shorten the service lifetime (e.g. avoid software-induced obsolescence, Kern et al. 2018).

A key concern here is obsolescence, which means that a device loses its functionality or usability due to ageing (Proske et al., 2016). Updating MIED software or hardware can render devices obsolete (Proske et al., 2016), e.g. software updates can reduce battery cycles, changes of physical interfaces can render accessory devices obsolete.

To *avoid software-induced obsolescence,* software applications are required to be compatible with different hardware and software configurations and software providers need to offer support services (Kern et al., 2018). Also, users could be informed about the consequences of a software update before installing it. Exemplary strategies to *avoid hardware-induced obsolescence* are to use durable materials (Proske et al., 2016) and open and commonly used interface standards (Schischke et al., 2016).

Software can be designed in a way which encourages users to use the device longer (*software-induced behavior change*). For example, a smartphone app can inform users about possible actions to increase the service lifetime close to expiration of the mobile network subscription (e.g. renewal of subscription without buying a new device, reselling or returning the device, Huang and Truong 2008).

The possibility to repair or replace components can increase the service lifetime of devices that are broken or no longer meet the requirements of the user (Nes & Cramer, 2005). Several design principles aiming at *improving reparability and upgradability* of MIEDs exist. For example, modularization improves "the composability of the final product from a set of standardized components" (Hankammer et al., 2018, p. 147) and thus the chance to replace broken or obsolete components with functioning or even more powerful components. *Design for upgradeability (*e.g. intentionally over-specifying some components, Inoue et al. 2016) or *design for reparability* are related approaches. The availability of spare parts and repair instructions is also essential for repairing a device (Vonplon, 2020; Wilhelm, 2012).

The durability of a product refers to how well a device is protected from wear and tear (Bocken et al., 2016). *Design for durability* “is about testing a product against assumptions about how the product is going to be used” (Schischke et al., 2016, p. 5). For example, some

smartphones shut down automatically when their core temperature gets too high.
Psychological obsolescence is obsolescence caused by subjective aging, e.g. due to fashion trends (Proske et al., 2016). *Increasing user attachment* to a device can encourage users to postpone replacement and handle devices more carefully (Sung et al., 2015). For example, ergonomic design can lead to increased user attachment to devices (Komeijani et al., 2016).
Design for reuse of components enables to reuse parts of a defunct device to repair other devices (Franklin-Johnson et al., 2016). Therefore, devices need to allow for disassembly and components need to be compatible with other devices (Nes & Cramer, 2005; Sawanishi et al., 2015).

Retention

Retention measures aim at increasing the time a user actively uses a device, e.g. by encouraging users to postpone the decision to acquire a new device.
In case of broken devices, this can be achieved by *providing users with the possibility to repair devices*. In many cases, users cannot repair the devices themselves because specialized knowledge, skills, and tools are required (Nes & Cramer, 2005; Sawanishi et al., 2015). Producers can actively contribute to these obstacles, e.g. by using screws for which screwdrivers are not publicly available (Sawanishi, Torihara, and Mishima 2015). Exemplary measures to support repair are the availability of repair instructions and spare parts (Vonplon, 2020).
Measures to *increase user attachment* to devices (also discussed in the section "Improve device design") exist, e.g. personalization or upcycling (Sung et al., 2015, p. 2) through engravings, buttons or stickers.
Many users are not aware of the environmental impact of hardware production. *Informing users about the environmental impact of device production* can persuade them to postpone replacement. Wilhelm (2012) suggests eco-labelling as a possible measure.

Recirculation

Recirculation measures aim at encouraging reuse of a used device by an additional user and/or in a different context. Successful recirculation always depends on user decisions at two life cycle stages at least: some users need to pass on or return their device and some users need to acquire used devices instead of new devices.
Reselling leverages the heterogeneity in consumer requirements, i.e. some consumers might be content with a device that is inadequate to another user in exchange for a lower price (Williams, 2003). This cascade use (Rudolf et al., 2020) can be fostered through device retailers or peer-to-peer marketplaces such as eBay (Williams, 2003). Often intermediaries overhaul smartphones, e.g. through refurbishment or remanufacturing (Mugge et al., 2017; Skerlos et al., 2003).
A common practice is to collect or buy back used and still-functioning MIEDs in industrialized countries and export these to lower-income countries (Sinha et al., 2016) or to *pass on* the devices to a friend or family member (Wieser & Tröger, 2018).
One barrier for reuse is that many consumers are still skeptical towards used products due to quality concerns (Wieser & Tröger, 2018). Thus, further measures to convince users and promote second-hand purchases are required (Gåvertsson et al., 2020).
An approach to promote reuse is the rental of devices (i.e. as a product-service-system or *device-as-a-service*) instead of selling them (Schneider et al., 2018). Once a user wants a new device, they return it to the service provider who still owns the device, can refurbish or remanufacture it and rent it out to another user.
Some authors also suggest to *repurpose obsolete devices* for use in a different context. For example, a mobile phone could be used as an entertainment device in a waiting room (Huang & Truong, 2008), or as an in-car parking meter (Zink et al., 2014).
When a MIED is no longer functional, the device usually contains still-functioning parts, which can be used to repair other devices. To *retrieve still-functioning parts/devices for reuse*, obsolete devices could be collected with mail back envelopes or at easily accessible drop-off points (Tanskanen & Butler, 2007). Design for reuse (see section "Improved device design") supports reuse of components.

Discussion

Implementation of measures

The measures we described strongly focus on structural solutions (e.g. by means of technical improvements) to extend the service lifetime of MIEDs. We do not delve into measures to change the consumer mindset (e.g. "less is

more", Miesler et al., 2018) or regulatory measures (e.g. extended producer responsibility).
In many cases, organizations trying to implement approaches for lifetime extension will face conflicting goals and interests. For example: Durable smartphones are often larger and heavier than their non-modular counterparts (Schischke et al., 2016). Improving the modularity of a smartphone can allow new companies to produce spare parts, and thereby "cannibalize" the revenues of original equipment manufacturers. Lifetime extension as such can also reduce revenues of manufacturers, as they are usually coupled to the number of devices sold.
Thus, systematic research on the feasibility of these measures and collaboration along the MIED value chain is needed to find creative solutions to mitigate these conflicts.

Environmental impacts of measures

A key requirement for realizing environmental gains through service lifetime extension is that it avoids the production of new devices. To date, there is little research about consumer acceptance of measures and the extent of actual lifetime extension (e.g. 1 year, 2 years). Additionally, existing research on the displacement rate of primary production by lifetime extension indicates that this does not occur on a one-to-one basis (imperfect substitution, Makov and Font Vivanco 2018; Zink et al. 2014; Zink and Geyer 2017), e.g. because used devices might be purchased by consumers who would not purchase a new device otherwise (Cooper & Gutowski, 2017). Also, re-spending effects can compensate for the environmental gains of lifetime extension (Jattke et al., 2020) if consumers increase their relative income (e.g. by postponing acquisition of new devices, by selling used devices, or by buying used instead of new devices) and direct that income to the consumption of other goods and services which are associated with environmental impacts as well (Makov & Font Vivanco, 2018; Zink & Geyer, 2017).
Service lifetime-extending measures can also lead to induction effects: adopting the measures induces activities which are associated with environmental impacts (e.g. shipping smartphones to repair facilities, Jattke et al. 2020).
Exporting obsolete devices to developing countries can also cause environmental impacts beyond energy consumption and GHG emissions because these devices are often informally recycled with harmful effects on people and the environment (Böni et al., 2015; Yu et al., 2017).

Conclusions

Extending the service lifetime of MIEDs can help to reduce the environmental impacts associated with the life cycle of MIEDs. Various potential measures exist that can be clustered into measures aiming at (1) improvements of device design, (2) retention and (3) recirculation.
While measures in all categories have been explored in literature, little is known about their effectiveness in achieving lifetime extension and reducing environmental impacts in practice. Reasons for this uncertainty are:

- Implementation of measures is challenged by diverse conflict of interests among actors in the MIED value chain, which often are caused by (expected) declines in revenues of manufacturers.
- Lack of research on consumer acceptance of measures and the degree to which the service lifetime is actually extended.
- The extent to which lifetime extension actually replaces primary production is uncertain (displacement rate).
- Re-spending effects and induction effects can diminish the environmental gains from lifetime extension.

Thus, more systematic research on the feasibility for implementing measures and the conditions under which such measures effectively contribute to reduction of environmental impacts of MIEDs is required.

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