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Consumer-oriented interventions to extend smartphones' service lifetime

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ABSTRACT

A promising strategy to reduce smartphones' environmental footprint is to increase their service lifetime, thereby reducing the demand for resource-intensive production of new devices. Most of the existing literature focuses on production-oriented measures, such as improving repairability, but what remains missing is a systematic overview of consumer-oriented interventions to extend smartphones' service lifetime. In this study, we applied the consumer intervention mapping approach by systematically identifying consumer decision situations along the smartphone life cycle and interventions that encourage consumers to make smartphone lifetime-extending decisions. We identify two main mechanisms to achieve lifetime extension: *retention* by increasing the time during which a user keeps a device, and *recirculation* by passing on a device to an additional user. Altogether, we identified 26 different types of interventions to induce consumers to make smartphone lifetime-extending decisions and structure these according to consumer-influence techniques, e.g., *informing consumers* about retention/recirculation options and environmental impacts caused throughout device life cycles, *persuading* consumers by creating emotional attachment, *nudging* consumers through product labels for secondhand devices, *simplifying* execution of lifetime-extending decision options through take-back programs, and *incentivizing* lifetime-extension through buy-back programs. These interventions' success in achieving lifetime extensions and reducing environmental impacts in practice depends on the degree to which they actually extend smartphones' service lifetime and reduce production of new devices (displacement rate), induction and re-spending effects associated with the interventions, and the interventions' implementation feasibility, which conflicts of interest in the smartphone ecosystem often challenge.

1. Introduction

While smartphones cause greenhouse gas (GHG) emissions during production and operation, more than 80% of life-cycle GHG emissions are caused during production (Hilty and Bieser, 2017; Jattke et al., 2020). Simultaneously, a smartphone's average service lifetime is much shorter than the technically feasible lifetime (Thi ébaud(-Müller) et al., 2018). Therefore, a promising strategy to reduce smartphones' environmental footprint is to increase their service lifetime, thereby reducing the number of devices produced.

Throughout a smartphone's life cycle, a consumer makes plenty of decisions—consciously and subconsciously—that reduce the phone's service lifetime, e.g., throwing away a broken device instead of repairing it, replacing a device early, or storing a replaced device instead of reselling it. Thus, increasing smartphones' service lifetime might be possible by changing consumers' smartphone consumption behavior. Still, most existing literature on extending smartphones' service lifetime takes a production-oriented approach by focusing on changes to device design or functionality (e.g., modular smartphones; Hankammer et al., 2018; Schischke et al., 2016), recycling and reuse of components (Janusz et al., 2016), providing device-related services (e.g., repair; Cole et al., 2016), or economic opportunities and challenges associated with lifetime-extending measures (e.g., business models for reselling or refurbishing smartphones; Bocken et al., 2016; Riisgaard et al., 2016).

However, some extant studies have examined consumers' smartphone behavior. For example, Martinho et al. (2017) and Thi ébaud (-Müller) et al. (2018) examined smartphones' existing service lifetime, Oguchi et al. (2016) examined consumers' desired service lifetime, Bookhagen et al. (2013), and Holmström and Böhlin (2017) and Wieser and Tröger (2018) examined consumer acceptance of approaches for

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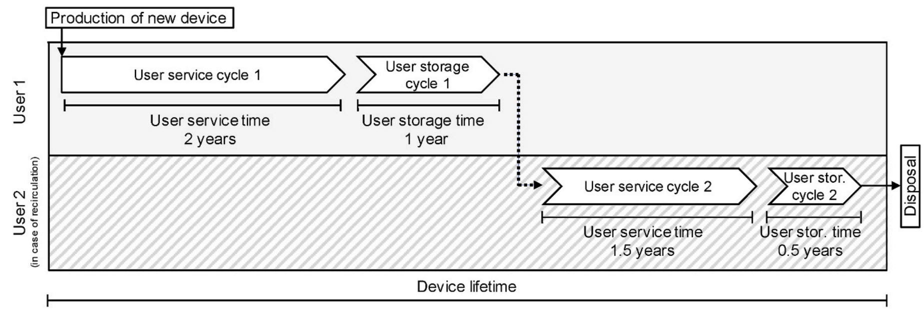

Fig. 1. Graphical illustration of a smartphone's life cycle and relevant terms. Please note that most devices are not passed on to a second user nowadays. In this case, the number of service cycles and storage cycles both would be two, the device service lifetime would be 3.5 years, the device storage time 1.5 years, and the device lifetime five years.

service lifetime extension. Some studies even investigated the efficacy of consumer incentives that intended to increase smartphones' service lifetime (Mugge et al., 2017; Poppelaars et al., 2020). These studies focused on a few selected lifetime-extending measures, such as returning or selling refurbished smartphones. Still, a comprehensive overview of consumer-oriented interventions—i.e., interventions intended to induce consumers to make choices that extend a smartphone's service lifetime—is lacking.

This study aims to address this gap by (1) systematically analyzing the smartphone life cycle, (2) identifying consumer decision situations that impact the service lifetime along the entire smartphone life cycle, and (3) identifying interventions that can induce consumers to make lifetime-extending decisions. The study's results provide a consistent and comprehensive framework of consumer decisions that impact smartphone service lifetime and consumer-oriented interventions to extend it. This framework helps researchers, policy makers, and organizations in the smartphone ecosystem (e.g., smartphone resellers, repair shops) systematically evaluate, compare, and prioritize consumer-oriented interventions to extend smartphones' service lifetime. Specifically, for organizations and policy makers in countries whose influence on smartphone production is limited (the largest smartphone producers are based in the US, China, and South Korea; Counterpoint, 2020), taking such a consumer-oriented approach to smartphone service lifetime extension can be promising.

This article is structured as follows: In Section 2, we examine extant research in the field and present our study's research questions. In Section 3, we describe our methods, and in Section 4, provide the results. In Section 5, we discuss the identified interventions and their potential implementation. We also discuss the environmental implications of service lifetime extension, considering that reducing environmental loads is its main purpose, and end the paper with the main conclusions in Section 6.

2. State of knowledge and research questions

In this section, we describe the smartphone life cycle, including consistent terminology (2.1); already-examined production-oriented measures (2.2); and consumption-oriented measures (2.3) to achieve service lifetime extension, then derive research questions based on the literature gaps identified (2.4).

2.1. Smartphone life cycle and lifetime

One challenge when comparing existing studies in the field is that the terminology that different authors use often is inconsistent. In this study, we used the following key terms, which were synthesized from existing literature (e.g., Thiébaud et al., 2017; Thiébaud (-Müller) et al., 2018). If different terms exist, or if we could not find an existing term, we tried to harmonize the terminology or propose new terms.

A *user service cycle* is a phase during which a dedicated user uses a device actively. *User service time* refers to the duration of one user service cycle, and *device service lifetime* is the sum of all user service times. A *user storage cycle* is a phase during which a dedicated user stores a device, *user storage time* is the duration of one user storage cycle, and *device storage time* is the sum of all storage times (storage is sometimes also referred to as *hibernation*). The *device lifetime* is the sum of the device service lifetime and the device storage time. Fig. 1 provides an example of a smartphone's life cycle with two users and two storage cycles, to illustrate important terms to describe the life cycle.

Mechanisms that lead to service lifetime extension can be categorized into *retention* mechanisms (increasing the time a user keeps a device) and *recirculation* mechanisms (passing on a device to an additional user). As such, *retention* extends the user service time and *recirculation* adds additional user service cycles. For example, retention can be achieved by repairing a device, while recirculation can be achieved by passing on the device to another user or returning the device to an intermediary who resells the device.

In principle, further smartphone pathways are possible, e.g., donation to charities (Sinha et al., 2016), repurposing smartphones for use in another context (Zink et al., 2014), or recycling device components (Cucchiella et al., 2015). However, these lie beyond this study's scope because the measures do not increase entire devices' service lifetime, but rather their individual components, and because they do not directly impact substitution of new devices. Thus, we consider the device to be near end-of-life (disposal) when it is handed over to a recycler, disposed of in municipal waste, donated, or repurposed. We also excluded the measure "intensifying the use of devices through device sharing" from this study because the flexible use of smartphones regarding time and place restricts opportunities for shared use of devices and because smartphones are personalized and have an emotional value with consumers.

Some studies have investigated smartphones' existing service lifetime and disposal pathways (Martinho et al., 2017; Thi ébaud(-Müller) et al., 2018). For example, Thi ébaud(-Müller) et al. (2018) found that after its first service cycle, 22% of mobile phones in Switzerland (most of which are smartphones today) are dropped off at collection points and only 15% are reused (second service cycle). Altogether, 58% of mobile phones are stored (e.g., at consumers' homes) after the first service cycle, 59% of these are dropped off at collection points after storage, and only 24% are reused. Altogether, only 29% of mobile phones in Switzerland reach a second service life, and 6% reach a third service life.

Low reuse rates for mobile phones after their first service cycles would not be an issue if the first service lifetime was already long. However, mobile phones' technically feasible service lifetime (some consumers use their mobile phones for more than nine years) is significantly longer than the average first service lifetime (3.3 years in Switzerland; Thi ébaud(-Müller) et al., 2018). Studies in other regions have yielded similar results (Glöser-Chahoud et al., 2019; Zhilyaev et al., 2021). Thus, a large number of smartphones is either disposed of too early or stored unnecessarily long, even though they are still functional.

Thus, reducing production of new mobile phones and their environmental impact by inducing consumers to use still-functional devices longer is quite possible theoretically.

2.2. Production-oriented measures

A large body of literature has examined production-oriented measures, many of which have focused on avoiding obsolescence (e.g., Bocken et al., 2016; Hankammer et al., 2018; Nes and Cramer, 2005; Proske et al., 2016; Schischke et al., 2016), i.e., when a device loses its functionality or usability due to ageing. Obsolescence can be further divided into material obsolescence (e.g., materials breaking), functional obsolescence (e.g., lack of interoperability between software and hardware components), psychological obsolescence (e.g., subjective ageing due to fashion trends), and economic obsolescence (e.g., due to high prices for repair; Proske et al., 2016). The practice of actively shortening product lifetime (e.g., by ending support for certain devices) is called planned obsolescence (Proske et al., 2016) and has been identified and fined in the smartphone industry in recent years (Murphy, 2020).

During the production stage, smartphone manufacturers can take measures to postpone smartphone obsolescence, such as using universal connectors or improving hardware durability (Bocken et al., 2016), e.g., through shockproof displays. Providing the possibility of repairing or upgrading devices (Cole et al., 2016; Riisgaard et al., 2016; Wieser and Tröger, 2018)—e.g., through modular smartphone design—also can postpone obsolescence. Modularity is "an approach that implies the composability of the final product from a set of standardized components" (Hankammer et al., 2018, p. 147), e.g., by allowing for replacement of broken or obsolete smartphone components with functional or more powerful components. Hankammer et al. (2018) and Schischke et al. (2016) distinguished between different types of modularity, e.g., add-on, repair, generic, or individual. Either consumers or specialized service providers can conduct device repairs or upgrades (Wilhelm, 2012). Providing the possibility of repairing devices requires not only suitable smartphone design, but also the provision of spare parts, repair instructions, and repair services (Bieser et al., 2021; Vonplon, 2020; Wilhelm, 2012). Furthermore, regulatory measures to improve reparability and upgradability aim to force producers to make spare parts available for longer periods of time, indicating a product's reparability on its packaging, increasing the warranty period, or shifting the burden of proof from the consumer to the manufacturer in case of defects (Vonplon, 2020).

Software installed on smartphones also can cause obsolescence, e.g., when software updates reduce battery cycles or when new software is incompatible with older hardware or software configurations (Bieser et al., 2021; Kern et al., 2018). Thus, to avoid obsolescence, smartphone applications should be compatible with various hardware and software configurations (Kern et al., 2018), software providers should offer long-term software support (Proske et al., 2016), and users should be informed about potential performance impacts before installing software updates (Bieser et al., 2021).

Once a smartphone is disposed of, materials or entire smartphone components can be recycled for use in another device or for another purpose (Cucchiella et al., 2015; Martinho et al., 2017; Sinha et al., 2016). However, for technical and economic reasons, not all materials contained in smartphones are recycled (Bookhagen et al., 2018; Buchert et al., 2012). Furthermore, many smartphones never enter formal recycling processes, but instead are recycled informally in Asia or Africa, which have even lower recycling rates and greater toxic impacts on humans and the environment (Bieser and Coroamă, 2021; Schneider, 2019; Yu et al., 2017). Another challenge in smartphone recycling is encouraging users to turn in their devices to recyclers. Renting out devices for a monthly fee (device as a service) instead of selling them can increase the return rate, as the device's ownership remains with the service provider (Schneider et al., 2018). This also might provide additional incentives for producers to manufacture more durable and repairable devices because revenues then are coupled with the service lifetime, instead of with the number of produced devices (Jattke et al., 2020).

2.3. Consumption-oriented measures

Consumption-oriented measures to extend smartphones' service lifetime focus on changing smartphone consumer behavior to affect lifetime-extending decisions.

One of the most discussed measures is increasing reuse of devices by encouraging consumers to purchase secondhand devices (Mugge et al., 2017) or to pass on unused devices to new users (Cole et al., 2016; Cooper and Gutowski, 2017; Wieser and Tröger, 2018). Reuse of a smartphone by another user leverages varying consumer requirements, i.e., some consumers might be content with a device that is inadequate for another user in exchange for a lower price (Williams, 2003). Reuse can be achieved through peer-to-peer handovers (e.g., by passing on a device to a friend or selling it in a marketplace, such as eBay) or with the help of an intermediary, such as a company that specializes in buying and reselling used devices. Already examined ways to collect stored and unused devices include, e.g., mail-back envelopes, buy-back programs, or take-back kiosks (Tanskanen and Butler, 2007). Intermediaries often overhaul smartphones (e.g., refurbishment, remanufacturing), thereby increasing their functionality and resale value (Mugge et al., 2017; Skerlos et al., 2003). Refurbishment aims to restore a device to a state that is acceptable for reuse, whereas remanufacturing may involve upgrading the device "beyond the specification of the original product when new" (Tan et al., 2014, p. 581). Some studies also have suggested repurposing (or upcycling) obsolete smartphones for use in other contexts, e.g., parking meters (Zink et al., 2014) or to educate students (Xun Li et al., 2010). Renting out devices instead of selling them (see also Subsection 2.2) also can promote reuse if service providers rent out used and returned devices to consumers with different requirements (Jattke et al., 2020; Schneider et al., 2018; Welfens et al., 2013, 2016).

Other measures examined in this field include increasing consumer attachment to devices (e.g., through personalization; Sung et al., 2015), increasing awareness of devices' environmental impacts (Ohnmacht et al., 2018; Welfens et al., 2016), making consumers aware of devices' projected functional lifetime through software (e.g., displaying the projected functional lifetime on each smartphone; Huang and Truong, 2008), and eliminating marketing practices that persuade consumers to replace their devices.

Still, most existing studies on consumer-oriented measures focus on few selected measures. No comprehensive overview has been conducted yet on interventions to induce consumers to make smartphone lifetime-extending decisions, even though consumers make plenty of decisions that directly reduce their service lifetime (e.g., throwing away a broken device instead of repairing it, replacing a device early, or storing a replaced device instead of reselling it). Such an overview is essential to evaluating and comparing interventions systematically to identify the most promising measures to extend lifetime.

2.4. Research questions

This study addresses the identified research gaps by answering the following overarching research question:

What are effective consumer-oriented interventions to extend smartphones' service lifetime?

We refined this question into the following specific research questions:

- RQ1 *What are the principal consumer decision situations in the entire smartphone life cycle that impact a smartphone's service lifetime?*
- RQ2 *What decision options are available to consumers, and what is their impact on smartphones' service lifetime?*

Phase	Method	Outcome
Review	– Review of scientific and gray literature on the smartphone life cycle, service lifetime-extending measures, consumer interventions and intervention techniques to increase the service lifetime	– Overview of the smartphone life cycle – Overview of lifetime-extending measures – List of interventions and intervention techniques
Concept-ualization	– Modeling of the smartphone life cycle with the event-driven process chain notation concept – Consumer journey and decision analysis – Consumer intervention analysis	– Model of the smartphone life cycle – Overview of consumer decision situations and options along life cycle – Overview of consumer interventions clustered by intervention technique and decision situation
Validation	– Two interdisciplinary expert workshops for validation and refinement	– Validated and refined framework

Fig. 2. The study's research approach.

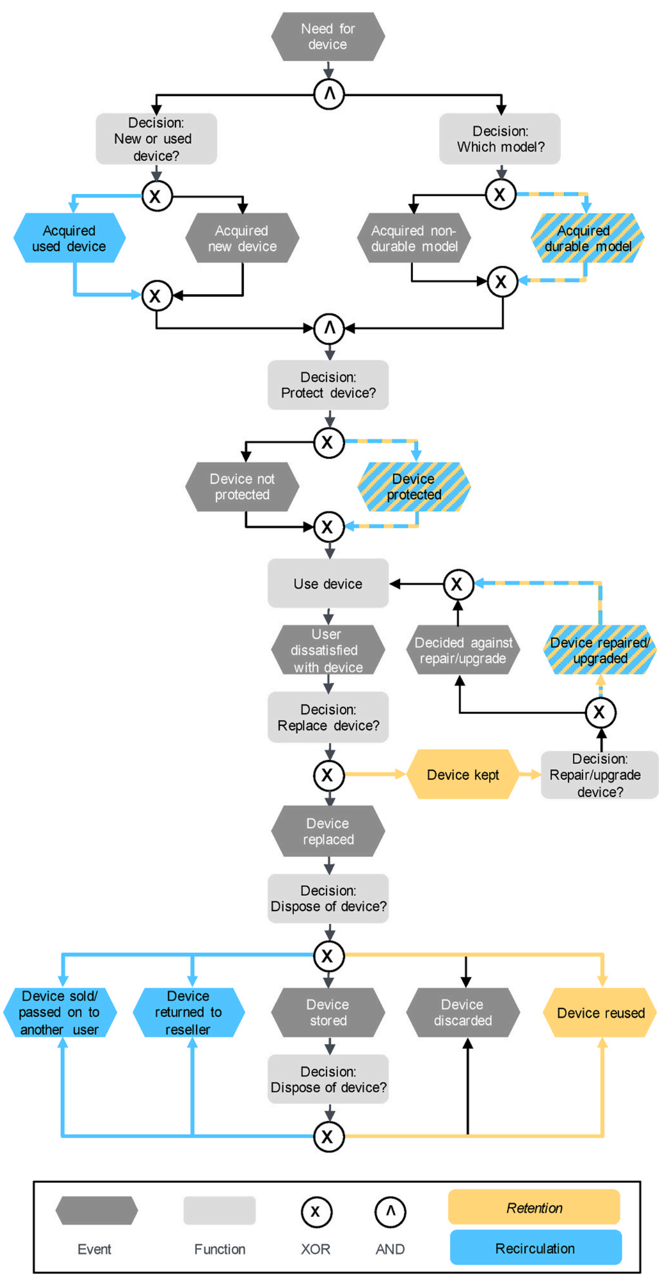

Fig. 3. The event-driven process chain of the consumer decision situations that impact the device's service lifetime.

RQ3 *What interventions that can steer consumers' choices toward decision options to extend smartphones' lifetime have been examined in literature and in industry practice?*

3. Materials and method

To answer the research questions, we followed the consumer intervention mapping approach by Sinclar et al. (2018, p. 1) to identify "the points within a product's life cycle where stakeholders are able to intervene in the product's expected journey." Our approach comprises three steps: (1) a *review* of the existing literature in the field; (2) *conceptualization* of the smartphone life cycle, user decision situations, and consumer interventions; and (3) *validation* of results. Fig. 2 provides an overview of the overall approach, which is explained in more detail below.

During the *review stage*, we identified and analyzed scientific and gray literature on smartphones' life cycle (e.g., Ercan et al., 2016; Thiébaud et al., 2017; Thiébaud (-Müller) et al., 2018), lifetime-extending measures (e.g., Bieser et al., 2021; Cole et al., 2016; Wilhelm, 2012), and possible consumer interventions and intervention techniques (e.g., Holmström and Böhlin, 2017; Ohnmacht et al., 2018; Sung et al., 2015; Welfens et al., 2016) to increase service lifetime.

During the *conceptualization stage*, we used the literature review's results to develop a smartphone life cycle model, including potential lifetime-extending mechanisms (e.g., repair, reuse), and we identified the states that a smartphone can assume throughout its lifetime (e.g., in production, in use, in repair). Based on the identified state transitions, we modeled the consumer journey and identified user decision situations that influence state transitions and the set of decision options available to consumers. To model the consumer journey, we used the event-driven process chain notation concept of the ARIS modeling language, which allows for modelling (business) process flows based on functions (e.g., decisions) and events (e.g., outcomes of decisions; Scheer, 2002). Furthermore, we clustered the consumer interventions identified during the review stage according to the decision situations and options that they influence and according to the consumer intervention technique (e.g., *informing, motivating, or nudging* users). Therefore, we applied a simplified version of the classification system of interventions to influence consumer behavior examined by Mosler and Tobias (2007) in the special case of smartphone lifetime extension.

To *validate* the framework, we refined and extended the life cycle model, consumer decision situations and options, interventions, and intervention techniques into two interdisciplinary expert workshops that took place virtually in November 2020 and May 2021. During the first workshop, seven researchers participated who all specialize in the field of smartphones' environmental impact and who are part of a three-year research project on lifetime extension of mobile Internet-enabled

Table 1
User decision situations, exemplary triggers of decision-making, decision options and their impact on the total service lifetime.

Decision situations	Description	Exemplary triggers	Decision options	Impact on device service lifetime
Which model?	User selects a smartphone model and may choose durable device	- User wants to replace current device - User wants an additional device	Acquire durable model	Potentially longer user service time (retention) or additional user service cycle (recirculation), as the device is more durable.
			Acquire non-durable model	No extension
New or used device?	User decides whether to purchase new or used device	- User wants to replace current device - User wants an additional device	Acquire new device	No extension
			Acquire used device	Additional user service cycle for used device (recirculation)
Protect device?	User can take additional action to protect device (e.g., protective covers)	- Acquisition of new/used device - Marketing campaign for protective case - Purchased phone comes with a protective device - Friend passes on a protective case	Protect device	Potentially longer user service time (retention) and/or additional user service cycle (recirculation), as the device is in better condition at end of user service cycle.
			Do not protect device	No extension
Replace device?	User considers replacing device	- Device does not meet user's requirements (device performance decreased or requirements increased) - Device is broken - Attractive offer for new device	Keep device	User service time increases (retention).
			Replace device	User service cycle ends. The impact depends on the decision when deciding whether to "dispose of device."
Repair/upgrade device?	User is not (entirely) satisfied with device and considers repairing or upgrading it	- Device does not meet user's requirements (device performance decreased or requirements increased) - Device is broken	Repair/upgrade device	Potentially longer user service time (retention) and/or additional user service cycle (recirculation) as the device is in better condition at the end of the user service cycle.
			Do not repair/ upgrade device	No extension
Dispose of device after replacement?	User decides what to do with replaced device	- User decides to replace current device	Discard device (e.g., in municipal waste, recycler)	No extension
			Store device	Impact depends on duration of storage and decisions after storage. However, the longer a device is stored, the less likely it will be reused.
			Return device to reseller	Additional user service cycle (recirculation) if reseller successfully sells device
			Pass on/sell device to another user	Additional user service cycle (recirculation)
Dispose of device after storage?	User is ending storage of device and is wondering what to do with it	- Through external triggers: marketing campaign for resale platform; friend needs a device - Without external triggers: user sees device in a drawer; user moves and wants to clear out household goods	Reuse device	User service time increases (retention)
			Discard device	No extension
			Return device to reseller	Additional user service cycle (recirculation) if reseller successfully sells device
			Pass on/sell device to another user	Additional user service cycle (recirculation)

devices such as smartphones.[1] During the second workshop, six additional experts with a wide range of backgrounds (telecommunications companies, sustainability consultancies, NGOs, startups, and research institutes) participated (see appendix).

4. Results

4.1. Consumer decision situations and options impacting smartphones' service lifetime

Fig. 3 lays out the event-driven process chain that illustrates the consumer journey, including user decision situations and options that influence smartphones' service lifetime. An "XOR" operator means that only one of the paths can be followed (e.g., a consumer can either decide to protect a device *OR* not protect it). An "AND" operator means that all the paths must be followed (e.g., a consumer must choose whether to purchase a new or used device *AND* select a model). Please note that alternative ways of illustrating or sequencing decisions are possible (e.g., a user could first select the model, then decide whether to buy a new or used device, or vice versa). Some decisions also are connected. For example, deciding whether to buy a new or used device and the choice of smartphone model are interrelated and influenced by various criteria, e.g., operating system or the cost of a new or used device.

User decisions impact device service lifetime in different ways. Table 1 provides an overview and description of all user decision situations, exemplary events that trigger the decision-making process, decision options available to users, and their impact on device service lifetime. This overview indicates that smartphone retention can increase if users decide to keep their devices, even though they are considering a replacement (e.g., because the smartphone does not fully satisfy their needs anymore), or if users protect their devices (e.g., with a protective case). Successful recirculation always depends on user decisions during at least two life cycle stages: Some users opt to pass on or return their devices (after use or after storage), while others opt to acquire used devices instead of new ones.

4.2. Consumer-oriented interventions to increase smartphone' service lifetime

In the literature review and workshop, we identified seven key consumer influence techniques (based on Mosler and Tobias, 2007) that can be divided roughly into three categories (Table 2), as well as 26 interventions that can be clustered according to the techniques

[1] http://www.nrp73.ch/en/projects/sustainable-behaviour/extending-the-lifespan-of-mobile-devices.

Table 2
Categorized consumer influence techniques to classify service lifetime-extending interventions.

Category	Description	Technique	Description
Person-oriented techniques	Changing individuals' intrinsic behavior-shaping factors	Inform/ educate	Inform and educate consumers about lifetime-extending decision options and their environmental consequences.
		Persuade	Change consumers' attitudes, norms, and values in favor of lifetime-extending behavior with logical arguments (argumentative persuasion), or create the desire for such behaviors (affective persuasion).
Situation-oriented techniques	Changing behavior-shaping factors in the situation in which an action is carried out	Nudge	Influence choices by changing the manner in which life-extending options are presented to people in a decision-making situation without prohibiting other options or significantly influencing their consequences.
		Simplify	Simplify information on lifetime-extending decision options and their implementation for consumers.
Structure-oriented techniques	Provide new decision options or change the consequences of behaviors	Incentivize	Provide a reward to consumers (mostly financial) for choosing lifetime-extending decision options.
		Enforce	Introduce regulations, binding standards, restrictions, or obligations that require consumers to demonstrate lifetime-extending behaviors, or other actors to implement lifetime-extending practices that, in turn, increase the probability that consumers will choose lifetime-extending decision options.
		Enable	Create new services or products for consumers that make it easier to adopt service lifetime-extending behaviors.

(Table 3).

Considering that person-oriented techniques aim to change individuals' intrinsic behavior-shaping attributes, they can impact every decision situation and option. However, situation-oriented techniques need to occur close to the moment of decision-making. Eventually, structure-oriented techniques, which involve a financial reward or new services, also are linked closely to decision-making situations. However, they might influence consumers before or after decision making, e.g., knowing that a device can be returned for a financial reward can prepone a replacement decision (Cooper and Gutowski, 2017; Scitovsky, 1994; Thomas, 2003). Structure-oriented techniques that enforce behaviors mostly concern smartphone manufacturers and retailers, as they entail the devices' technical features or the retail offer's specific design (including additional services) that, in turn, influence consumer decisions.

5. Discussion and answers to research questions

In this section, we discuss consumer-oriented interventions (5.1), possibilities for and challenges to their implementation (5.2), and environmental implications of lifetime extension (5.3), as well as suggest directions for further research.

5.1. Consumer-oriented interventions

Altogether, we identified 26 interventions that aimed to encourage smartphone consumers to choose service lifetime-extending decision options. These can be clustered into (1) person-oriented techniques, (2) situation-oriented techniques, and (3) structure-oriented techniques. Even though each intervention was assigned to one of these techniques, interventions are, in practice, often based on a combination of various techniques (e.g., an information campaign informs consumers, but often also tries to persuade them toward a specific direction). Thus, the overview of interventions should be viewed as a means to an end—helping to identify and compare possible consumer-oriented interventions to extend smartphones' service lifetime—not as an end in itself.

Furthermore, the overview provides a basis for systematically comparing interventions. In fact, few studies empirically have tested or evaluated interventions, and further empirical research is needed to identify interventions that are most effective at extending lifetime. An intervention's efficacy depends on whether it actually leads to consumers increasingly choosing lifetime-extending decision options and the degree to which the service lifetime actually is extended (e.g., one year, two years). External factors also influence this, such as the launch of new device generations and associated marketing activities that can encourage early replacement of devices (Rizos et al., 2019). In fact, it has been demonstrated that the desire for something new often reduces smartphones' service lifetime, which marketing campaigns can impact by creating such a desire and changing the relative cost of keeping or replacing a device. Both factors influence replacement decisions and are interrelated (Jaeger-Erben et al., 2021).

5.2. Implementation of interventions

The smartphone ecosystem comprises several actors, e.g., companies involved in device hardware production (e.g., producers, component suppliers), software providers (e.g., for mobile operating systems or apps), retailers, mobile network carriers, modification service providers (e.g., repair shops), resale marketplace providers, collectors or policy makers (based on WIPO, 2017). An important question is which actors have the wherewithal to implement which interventions. Generally, interventions closely linked to the decision-making situation (e.g., nudge or simplify) can be implemented by actors in direct contact with consumers during the decision-making process (e.g., retailers, mobile network providers, collectors, repair shops). The possibility of actors who are not directly involved in the decision-making process (e.g., NGOs, policy makers) influencing consumer behavior during decision making is limited. However, these actors can change consumers' intrinsic behavior-shaping factors (e.g., through information campaigns or affective persuasion; Mosler and Tobias, 2007) or establish structures that alter decisions' consequences (Mosler and Tobias, 2007), such as banning and punishing smartphone disposal in municipal waste.

In many cases, one organization can assume the role of various actors (e.g., Apple is a producer, software provider, service provider, and retailer; WIPO, 2017); thus, they have more possibilities to influence consumers along the smartphone life cycle. However, they often face conflicts of interest regarding lifetime-extending interventions. For example, making repair instructions and spare parts publicly available can allow companies other than the original equipment manufacturers (OEMs) to develop and sell compatible spare parts, thereby cannibalizing their own revenues. Nudging consumers toward keeping their devices at the acquisition decision can affect manufacturers and retailers' revenues negatively (Bieser et al., 2021). However, practical solutions to mitigate such target conflicts are available. For example, Jensen et al. (2021) suggested that companies that offer long-lasting products can include longevity in their branding and extend their warranties, thereby increasing revenues through lifetime extension. Service-based business models that allow for decoupling revenues from production of new devices also make lifetime extension compatible with economic targets (Bieser et al., 2021). In fact, companies that rent out instead of sell devices potentially could outperform traditional

Table 3
Interventions intended to induce consumers to make decisions that extend smartphones' total service lifetime, clustered by consumer influence techniques and the decision options they promote. An "x"/"(x)" indicates that the intervention has a major/minor impact on the decision option. "Enforce" interventions either can address consumers or producers and indirectly impact consumers. For example, policy makers and producers need to implement mandatory modularity, as it will incentivize consumers to repair their devices.

Category	Technique	Intervention	Decision options					
			Acquire used device	Acquire durable device	Keep/reuse device	Pass on device	Return device	Protect device
Person-oriented techniques	Inform	Information campaign (e.g., events on smartphones' env. impact)	x		x	x	x	x
		Information tool (e.g., app, website on smartphones' env. impact)	x		x	x	x	x
	Persuade	Design for attachment (e.g., through personalization or upcycling)			x			
		Marketing campaign (e.g., an ad for used devices)	x	x		x	x	x
		Users' voluntary self-commitment (e.g., to keep device longer)	x		x	x	x	x
Situation-oriented techniques	Nudge	Product label (e.g., for used or long-lasting devices)	x	x		(x)	(x)	
		Software-based reminders (e.g., app displays projected lifetime)	x		x	x	x	x
	Simplify	Collection campaign	(x)				x	
		Easy and accessible return channels	(x)				x	
		Provide mail-back envelopes in packaging to return devices	(x)				x	
		Increase offer of used devices through retailers' self-commitment	x				x	
		Data-cleansing service to ensure data deletion	(x)			x	x	
Structure-oriented techniques	Incentivize	Product-service-systems by renting instead of selling devices	(x)				x	
		Financial rewards for return (e.g., buy-back programs)	(x)				x	
		Mobile subscription discounts if device is kept at subscription renewal			x			(x)
		Bundles of subscriptions and used devices	x					
		Local action groups (e.g., incentivized through social contacts)	x	x	x	x	x	x
	Enforce	Extended producer responsibility (producer focus)			(x)		(x)	
		Mandatory modularity/reparability (producer focus)	(x)	x	(x)	(x)	(x)	
		Mandatory software backward compatibility (producer focus)	(x)		(x)	(x)	(x)	
		Advanced repair fee (producer focus)	(x)		(x)	(x)	(x)	
		Prohibition of disposal in municipal waste (consumer focus)					x	
	Enable	Easily accessible modification services (e.g., for repair or upgrade)	(x)	(x)	x	(x)	(x)	
		Easily accessible spare parts and repair instructions	(x)	(x)	x	(x)	(x)	
		Offering long-lasting devices (e.g., robust, repairable devices)	(x)	x	(x)	(x)	(x)	
		Easily accessible, user-friendly resale marketplace	x			x		

smartphone retailers: First, customer loyalty can increase if a company enters into long-term contracts with its customers. Second, the cost of goods sold (or rented out) decreases because returned smartphones easily can be rented out to other customers, thereby contributing to revenue generation without creating production costs. Whalen (2019) added that when firms continue to interact with products after they have been handed over to customers (as in the case of rented smartphones), companies have more possibilities to influence resource efficiency and create added value for customers, e.g., by guaranteeing minimum qualities. Finally, production-oriented measures also provide the possibility of extending service lifetime without creating conflicting targets. For example, modular smartphones are easily repairable and can create demand, thereby increasing sales of spare parts.

5.3. Service lifetime extension's environmental implications

A key requirement for realizing environmental gains through service lifetime extension is that it avoids production of new devices. Existing research on the displacement rate of production of new devices through lifetime extension indicates that this does not occur on a one-to-one basis. Some researchers even have stated that the rate is close to zero (Geyer and Doctori Blass, 2010; Skerlos et al., 2003; Zink et al., 2014). Reasons may include (1) consumers purchasing used devices as secondary ("spare") devices (Makov and Font Vivanco, 2018), (2) sellers of used devices replacing their devices early to maximize earnings from device sales (Cooper and Gutowski, 2017), (3) less-affluent consumers replacing their devices with used ones early (Cooper and Gutowski, 2017), (4) retailers lowering prices of new products to generate revenues from sales of used products (Cooper and Gutowski, 2017; Ovchinnikov et al., 2014), or (5) device makers' increased marketing efforts (Zink and

Geyer, 2017). These mechanisms, which may cause a low displacement rate, further indicate the need for consumer-oriented measures to extend smartphone lifetime because as long as phone makers' revenues are tied to the number of devices produced, it is improbable that they will take measures to reduce device sales.

Measures for extending smartphones' service lifetime also can induce activities associated with environmental impacts (induction effects, Bieser et al., 2020). For example, passing on devices directly to other users can cause environmental impacts, particularly if delivery is facilitated via motorized transport. Re-selling devices also can cause delivery impacts and impacts associated with the re-selling organization's operations. Any measure that involves repairing or upgrading devices also causes environmental impacts for producing the required spare parts. Existing research on GHG impacts of lifetime-extending measures has demonstrated that transport impacts are small compared with the production of new devices and that common repairs (e.g., display, battery) cause significantly fewer GHG impacts than producing entirely new devices (Jattke et al., 2020).

Finally, re-spending effects also can compensate for environmental gains from lifetime extension (Jattke et al., 2020). These occur if consumers increase their relative income (e.g., by postponing acquisition of new devices, selling used devices, or buying used instead of new devices) and direct that income toward consumption of other goods and services associated with environmental impacts (Makov and Font Vivanco, 2018; Zink and Geyer, 2017). Makov and Font Vivanco (2018) have argued that GHG impacts per monetary unit are relatively low for smartphones and that shifting consumption from smartphones to other goods and services is likely to elicit large re-spending effects. To counteract this effect, average GHG emission intensity from consumption in an economy needs to be reduced, which could be achieved by increasing taxation of non-renewable resources and decreasing taxation of renewable resources and labor (Makov and Font Vivanco, 2018; Ottelin et al., 2020).

6. Conclusions

Throughout a smartphone's life cycle, consumers make many decisions that can reduce the smartphone's service lifetime directly. We applied the consumer intervention mapping approach by systematically identifying consumer decision situations that impact a smartphone's service lifetime along its life cycle, as well as interventions intended to encourage consumers to choose lifetime-extending options. The result is a consistent framework of consumer decisions that impact the smartphone service lifetime and consumer-oriented interventions to encourage choices that lead to longer lifetime. We found many potential interventions to encourage consumers to make lifetime-extending decisions along the entire smartphone consumer journey. These rely on (a combination of) diverse consumer-influence techniques, including person-oriented techniques (*informing* or *persuading* consumers), situation-oriented techniques (*nudging* consumers or *simplifying* execution of lifetime-extending decision options), and structure-oriented techniques (*incentivizing*, *enforcing*, or *enabling* lifetime extension).

Given the need to reduce smartphones' environmental footprint and the vast number of intervention techniques, more research on the efficacy of interventions to extend lifetime and reduce environmental impacts in practice is required. Such research needs to consider:

(1) *Lifetime impacts:* To evaluate the efficacy of lifetime extension interventions, future studies must assess interventions with respect to (i) the degree to which they induce consumers to choose lifetime-extending decision options increasingly, and (ii) the degree to which the service lifetime actually is extended.
(2) *Environmental impacts:* Even if an intervention extends a smartphone's lifetime, to understand net environmental impacts, future research needs to account on (i) the displacement rate, i.e., the degree to which lifetime extension actually avoids production of new devices; (ii) induction effects, i.e., activities caused by interventions and their own environmental impacts (e.g., repair or transport of devices); and (iii) re-spending effects, i.e., environmental impacts from redirecting money saved or earned through lifetime extension to consumption of other goods and services.
(3) *Implementation feasibility:* Given the vast number of actors in the smartphone "ecosystem" (e.g., manufacturers, software providers, retailers) and the fact that many of these face conflicts of interest with regard to extending lifetime (e.g., manufacturers' revenues are coupled with the number of new devices produced), future research is needed to assess the feasibility of implementing interventions and finding creative solutions to mitigate conflicts.

To date, very few extant studies have evaluated interventions regarding these criteria empirically. We hope that this article will trigger such research and that the framework that we proposed will help researchers, policy makers, and organizations in the smartphone digital ecosystem (e.g., smartphone resellers, repair shops) systematically evaluate, compare, and prioritize consumer-oriented interventions to extend smartphone service lifetime. This will be an important step in reducing the environmental impact of our increasingly digitalized society and in decoupling digitalization from environmental impact.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table 4 provides an overview of the function and background of the participants of the second validation workshop.

Table 4
Overview of the function and background of the participants of the second validation workshop.

#	Function	Type of organization
1	Sustainability specialist	Telecommunication industry
2	Founder and general manager	Intermediary specialized in buying and reselling used devices

(*continued on next page*)

Table 4 (*continued*)

#	Function	Type of organization
3	Co-founder	Circular economy startup for electronic devices
4	Energy and sustainability specialist	Consumer protection agency
5	Senior researcher sustainable production and consumption	Research institute
6	Life cycle assessment expert	Environmental NGO

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