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Smartphone repairability indexes in practice

Linking repair scores to industrial design features

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Abstract

Policymaking mediates the relationships between manufacturers and consumers, thus defining the boundaries for the philosophies of production set forth by major companies. Research states that policymaking falls short in addressing the waste issues, natural resources consumption, greenhouse gas emissions, and other negative impacts posed by premature obsolescence; only recently have the "right-to-repair" guidelines demanded by environmental organizations and communities of citizens been included in policymaking. The introduction of the Index of Repairability in France as information at the point of sale aims to inform consumers and support their decision-making in purchasing more repairable products. In this paper, we consider the two Indexes of Repairability publicly available to consumers—in the French legislation and iFixit—and assess their application to smartphones from three manufacturers. The study establishes links between the scores and the industrial design features that promote or hinder repairability, service factors and information for self-repair, authorized repair, and independent repair. Data collection considers the available information for consumers and citizens by using netnography and secondary data from manufacturers, policymakers, and communities of users. Our findings suggest that higher scores that indicate easier repairability are not limited to product architectures that follow design for disassembly guidelines. Smartphones that are difficult to repair can still score high, and thus be perceived as easier to repair, if manufacturers provide high quality and affordable service. This paper discusses the results of the ongoing development of repairability scores for smartphones, thus suggesting paths for future research to improve methods and policies to support a longer lifetime of products.

KEYWORDS
circular economy, Index of Repairability, industrial ecology, policy analysis, product design, smartphones

1 INTRODUCTION

When our smartphone fails, we search for the fastest and/or most convenient option to restore it to a functional state. This choice has a direct impact on the product lifecycle. Considering that such a choice is taken by millions of users, it shapes consumption patterns, which occur under sets of options provided by manufacturers and regulated by policies.

Repairability is the first step toward an extended product lifetime, and together with maintenance can provide economic sustainability for a model of production and consumption based on a decreased rate of product replacement (Cooper, 2005). Design decisions made in the design and production phases have the most impact on greenhouse gas emissions in the smartphone industry (Cordella et al., 2021), and smartphones are ubiquitous, with more than 165 million units sold in 2020 in Europe (Statista, 2021b).

The present research links reparability of smartphones to decisions taken in the industrial design of the product, by analyzing two publicly available Indexes of Repairability (IoRs): the iFixit Index of Repairability (IoR) and the French-legislation Index of Repairability (IoR). The iFixit IoR is an online, community-based tool that informs consumers about the ease of self-repair activities. The French-legislation IoR is a policy that pushes manufacturers to communicate their products' ease of repairability to consumers. Both IoRs fit the premise that if a consumer can select a more repairable smartphone (i.e., one that has a higher repairability score) then the product may last longer, thus decreasing the negative environmental impacts associated with the short lifespan of smartphones (Cordella et al., 2021; European Commission, 2020). By comparing these two IoRs, we can assess how the demands for repair policies made by consumers' associations are adopted in the French IoR and establish correlations with information that is widely adopted by consumers who use the iFixit IoR. Our enquiry focuses on selected smartphones from two manufacturers leading the European market and from a manufacturer aiming to develop highly repairable smartphones. Our analysis aims to identify the technical drivers for scoring high in repairability and to link these to decisions taken in the industrial design phase of smartphones.

This research addresses the identified gap in alignment between policymaking and scientific knowledge (Heiskanen et al., 2014), by assessing the implementation and ongoing development of repairability scores for smartphones.

The results suggest paths for future research to improve methods and policies to support a longer lifetime of products and discusses the specific role of IoRs in raising awareness toward more sustainable patterns of consumption and production.

2 LITERATURE REVIEW

2.1 Repair and production philosophies

A production philosophy starts with trial and error in the engineering process and evolves into a state of maturation when both manufacturing and management visions are aligned in a coherent methodology that embodies a certain vision (Koskela, 1992). The prevalent production philosophy applied by major companies in the smartphone industry relies on continuous sales, a condition that is closely connected to what Packard (2011) considered as being part of a "hyperthyroid economy that can be sustained only by constant stimulation.". Prolonging the lifespan of smartphones is a cornerstone of meeting the UN goals for sustainable production and consumption. The premature replacement of smartphones should be investigated under the following factors (Cordella et al., 2021): the socio-economic and technical reasons leading to the replacement of the devices, the frequency and causes of failure, the frequency of upgrade operations, and the barriers hindering repair operations and expected functionality. Repair can be improved in the design phase with a design for disassembly approach for key modules, in the market phase by providing access to services and information, and in the use phase through consumer education by providing information on the use, maintenance, and repair of smartphones.

Barros and Dimla (2021) categorize the causes for premature replacement of smartphones into three interrelated tiers: hardware, firmware, and software. Hardware-related issues include parts engineered to a certain life cycle (e.g., the number of charging cycles for a battery), complex product architectures, joining methods that hinder the repairability and upgradeability of devices and the resistance of parts to use (e.g., accidental drops) (Cordella et al., 2021).

Firmware enables the configuration and interoperability of hardware parts. Firmware obsolescence comprises practices that limit product usability even after successful hardware repair by using part serialization, part pairing, and remote updates. Part serialization is the attribution of a unique numbering code to each mass-produced part (Thakur & Breslin, 2020), whilst part pairing is locking in the interoperability to specific serialized parts (Mikolajczak, 2021). The remote update of firmware enables improvement of the security of devices; however, in the context of obsolescence, it enables the disabling of the functionality of parts that do not belong to a specific part pairing.

Software obsolescence (Bartels et al., 2012) comprises updates that slow down devices or create incompatibility between operating systems and running applications (Sandborn, 2007).

The circular economy (Webster et al., 2017) challenges production philosophies relying on continuous sales and premature replacement by providing a framework that enables products to last longer. Circularity levels include an interconnection between repair, reuse, remanufacturing, and recycling. Repair and reuse can be performed by the user or by accessing services that extend the product's technical lifetime. Remanufacturing enables, amongst other factors, manufacturers to spend 80% less energy than manufacturing a new product and users to acquire more affordable products usually 30%–40% cheaper new versions of the same product (Hatcher et al., 2011). The circularity levels of reuse, repair, and remanufacturing are preferable to recycling according to the waste hierarchy, as they reuse parts that are still in working conditions thereby preventing recycling or disposal in landfill.

Circular economy practices require new business models (Bocken et al., 2016), product development methods that consider multiple cycles (Sumter et al., 2020) and an alignment between the market, the legislation, and product typology that supports product life extension (Bakker et al., 2014). Implementing circular businesses in the smartphone industry requires the improvement of take-back systems, consumers being informed about their rights, and design for easier repairability and upgradeability (Watson et al., 2017). Cordella et al. (2021) suggested that trade-offs between reliability and repairability aspects may include the availability of screen and case protection, smart battery management software, longer-term software support, support regarding personal data management, extended guarantees, availability of spare parts, and the provision of repair and maintenance information.

2.2 | Repair and policymaking

The "right-to-repair" broadly refers to the concept of allowing end users, business users, and consumers to freely repair these products in case of failure. Reaction to premature obsolescence often comes from two types of organizations advocating for "right-to-repair" products (Right to Repair, 2020). The first of these constitutes community repair associations, such as Repair Café, iFixit, or the Restart Project, where users share their knowledge about repair activities, thus overcoming the lack of knowledge made available by manufacturers (Federal Trade Commission, 2021). On the other hand, there are environmental non-governmental organizations (Right to Repair, 2020) that call on policymakers to act and develop legislation that (i) establishes design guidelines for disassembly, repairability, and reliability; (ii) guarantees access to spare parts and third-party repairers; and (iii) communicates product repairability to consumers before purchase.

Milios (2021) suggested that there is a need for an overarching policy framework that prioritizes reuse to provide a clear push for a more circular economy. Such a framework would be implemented in an evolutionary way through a consistent bundle of policies that would be setting both requirements and targets for reuse. Regarding repair in particular, only four member states in the European Union—Finland, Ireland, Sweden, and the Netherlands—provide legal provisions on guarantee and repair for more than the minimum period of 2 years (van den Berge & Thysen, 2020).

In the United Kingdom, for example, the government introduced in 2021 new standards that they hope would boast and give consumers a new legal "right-to-repair." The updated Ecodesign and Energy Labelling Regulations (DBEIS, 2021) legally requires manufacturers to make spare parts available to consumers and third-party companies and at its core is the aim to extend the life cycle of a range of devices and appliances by up to 10 years. However, the legislation specifically excludes smartphones and laptops. According to the Green Alliance (Peake & Vallauri, 2021), the legislation does not address the information barrier for consumers or the cost issues, and these are two of the key barriers to repairing products.

In a recent survey (Anelli & Morgado, 2021) conducted in five European countries—Belgium, France, Italy, Portugal, and Spain—45% of the surveyed consumers stated that at the moment of buying, their expectation of the length of time they would use their smartphone is between 4 and 5 years. Thirty percent of the respondents affirmed that repair-related issues were the main motivation for buying a new device. The battery, the display, and more recently, the back cover, together with software, can be key causes of failure leading to the premature replacement of smartphones (Cordella et al., 2021; Spiliotopoulos et al., 2022). The need for informing the consumer about the repairability of a range of electric devices has been researched in academia (Bracquené et al., 2021), implemented as a technical standard (Austrian Standards, 2014), and a European Repair Scoring System (RSS) developed for general products (Cordella et al., 2019). The RSS was developed after a review of 12 existing repair methods and the calculation of the proposed parameters enables three outputs to be assessed: (1) design for disassembly, (2) the repair and upgrade processes, and (3) the overall extent of reparability and upgradability of a product. The general methods defined in the RSS have been updated and tailored for product-specific applications in smartphones and tablets (Spiliotopoulos et al., 2022). The methodology of the study encompassed calibration and validation of the developed scoring system to enable its future implementation and application in other extended lifetime strategies such as reuse and update.

So far, only two score systems—the iFixit IoR and the French IoR—have been implemented in practice, providing comprehensive information directly to consumers regarding repair activities, enabling them to make a conscious decision on buying a more repairable device. In January 2021, France implemented the first European scoring system, the Index of Repairability (IoR), as a label at the point of sale of products disclosing direct information to the consumer about the repairability of the product (MTE, 2020). The IoR assesses the repairability of five types of electronic products: smartphones, laptops, televisions, washing machines, and lawnmowers.

This paper builds on the idea of the continuous assessment of policymaking (Milios, 2021) and scientific enquiry on policymaking (Heiskanen et al., 2014) by analyzing the structure of the French IoR and comparing it to the iFixit IoR, with the goal of identifying the drivers that enable a smartphone to achieve a high score and what differentiates a relatively higher score from a relatively lower one.

FIGURE 1 The five levels of the Index of Repairability (IoR) in the French legislation. *Source*: Indice de réparabilité (2023).

TABLE 1 The Index of Repairability (IoR) score range and respective repairability levels in the French legislation. Adapted from Légifrance (2023).

Color	Score range (min.–max. value)	Repairability level
Red	0–1.9	Very difficult
Orange	2–3.9	Difficult
Yellow	4–5.9	Moderate
Light green	6–7.9	Good
Dark green	8–10	Excellent

3 | RESEARCH METHODOLOGY

This study addresses the hypothesis that IoR both inform consumers in their selection of long-lasting smartphones (higher scores indicate easier and more repairable devices) and push manufacturers to design more repairable products, thus promoting more sustainable consumption and production patterns. To verify this hypothesis, we analyze selected smartphones of Apple, Samsung, and Fairphone. Apple and Samsung are the leaders of the European smartphone market, holding 61% of the share (Statista, 2021a), and therefore have a significant impact on how the market operates. Fairphone is a manufacturer that aims at introducing fairer relationships within the smartphone supply chain (Akemu et al., 2016). The reason these three manufacturers were selected is because (a) Apple and Samsung are leaders of the market, direct competitors, each with its own set of values; and (b) Fairphone brings the goal of introducing a more sustainable production philosophy to the smartphone industry and considers repair as an important value.

The analyzed smartphone models were released in 2019 and 2020 by the three manufacturers. During this period, Apple released a total of eight models, Samsung released nine (in the high-end segment), and Fairphone released two models. The models are all in direct competition market segments, from the top midrange to the high-end range. From our initial analysis of the 19 models, we selected 7 in the highest and moderate tiers of repairability for further analysis. The analysis of a reduced sample in the midrange to the high end and the selection of manufacturers that have a large market share enables addressing a significant part of the market with few products, following the methodology for smartphone analysis defined by Flipsen et al. (2019). Furthermore, the average score of the seven selected smartphones in the French IoR is 6.3, which is comparable to the average of 6.5 reported in the study that calculated the score of 550 models in the French IoR (HOP, 2022).

Our analysis of smartphones compared the IoRs from iFixit and from the legislation introduced by the Ministry of Ecological Transition (MTE) in France. The scores were analyzed regarding technical aspects of industrial design, such as joining methods and overall product architecture. The analysis aims to clarify the following research questions:

1. What contributes to the difference between a relatively higher score from a relatively lower one?
2. What contributes to the achievement of a high score?

Data collection uses netnography (Kozinets, 2009) and information from iFixit repair guides, manufacturers' websites, and the MTE in France.

4 | THE STRUCTURE OF THE INDEXES OF REPAIRABILITY

4.1 | The IoR in French legislation

Between 2017 and 2020, stakeholders in France discussed measures to create an anti-waste legislation framework (MTE, 2020), and the IoR is one of the practical tools to promote sustainable consumption (MTE, 2020). The IoR is a label at the point of sale with information for the consumer (Figure 1) that displays a score between 0 and 10, where 10 accounts for maximum ease of repairability. The numeric score is displayed together with a colored graphical element, in which each of the five colors corresponds to an interval, as detailed in Table 1.

Manufacturers calculate the IoR of their products based on predefined Excel spreadsheets made available by French authorities (example in Table 3). It is a conversion, divided by 10, of the score originally calculated out of 100 points. The IoR encompasses five criteria (referred to as acronym CT#) of equal weight (20%), some of which are further divided into sub-criteria with specific coefficients (Table 2):

- CT1: Documentation
- CT2: Disassembly, tools, and fasteners
- CT3: Availability of spare parts
- CT4: Price of spare parts
- CT5: Update and remote assistance

4.2 | The iFixit IoR

iFixit (2022) is a website created in 2003 as a reaction to Apple's lack of documentation concerning repair instructions. Its founders started by developing step-by-step repair guides and distributing them freely on the internet. All guides include time estimates for each activity, required tools, images of key steps, descriptions of the steps required, and a final review highlighting the strengths and weaknesses of industrial design decisions concerning repairability.

Users develop repair guides according to the guidelines defined by iFixit. The repair guides are licenced under the open-source Creative Commons licence, so other users may participate in reviewing and modifying the guides in collaborative ways. Final qualitative assessments are made by iFixit staff and/or repairers based on their peer-reputation score within the iFixit community.

There are general disassembly guides and specific guides for part replacement. In 2009, the general repair guides were supplemented with an IoR. The IoR was the first score system to assess and rank the ease of self-repair of consumer electronics to users. The score uses integral numbers from 0 to 10, with 10 being the easiest repair. The score is communicated together with a color system (Table 4).

4.3 | A comparison between the French IoR and the iFixit IoR

iFixit was consulted in the development of the French IoR, and there are structural similarities between the 0-to-10 scoring system and the color system. Table 5 shows the difference in the score structures; iFixit scores in integers, and the French IoR utilizes ranges with fewer tiers.

Regarding application and scope, the iFixit IoR is used in the context of procedural self-repair guides for final users. The score calculation is based on a qualitative assessment evaluating the ease of repair, considering an estimate time to disassemble and reassemble the smartphone. The French IoR is used in the context of the legislation and, more specifically, to inform consumers prior to their purchase. The score calculation was done by companies based on specific criteria categorized into five areas. Table 6 summarizes the overlaps between the two IoRs. The iFixit IoR fully overlaps the scope covered by CT2 in the French IoR and extends it by including a qualitative assessment of the repair time.

5 | ANALYSIS OF THE INDEXES OF REPAIRABILITY OF SMARTPHONES

We conducted a comparative analysis between the scores of the French IoR and the iFixit IoR on selected smartphones. The qualitative assessment aims to provide insights with respect to the impact of the five criteria in the final score in the French IoR, with a particular focus on CT2 and CT5. The assessment of CT2 provides clues for further enquiry into industrial design features' influence on repairability; thus, these features are directly related to hardware failure (Barros & Dimla, 2021; Cordella et al., 2021; Flipsen et al., 2019). The assessment of CT5 enables the consideration of practices that fall within the scope of firmware and software obsolescence (Barros & Dimla, 2021; Sandborn, 2007).

Table 7 shows the selected smartphones and their respective IoR given by iFixit and the French legislation. The French IoR is further detailed by criteria and sub-criteria.

5.1 | Characteristics of moderate repairability

The iPhone 11, the Samsung Galaxy S10, S20, S20 Ultra, and S20+ are classified under the same tier of moderate repairability in the French IoR. In the iFixit IoR, the iPhone 11 scored a 6 while all Samsung models scored a 3 in a lower tier.

TABLE 2 Overall structure of the Index of Repairability (IoR) in French legislation. Adapted from MTE (2022).

#	Criteria	Weight factor in the score	Score characteristics	Additional information
CT 1	Documentation and commitment for its update over time	**2**	• Ordinal scale with four levels per parameter • Zero if there is no commitment or if it is less than 4 years • Maximum when the commitment is 7 or more years	58% of the score consists of instructions for self-repair, such as technical manuals for repair. 42% of the score addresses professional repair documentation, such as component identification, wiring diagrams, or diagnosis information.
CT 2	Disassembly, accessibility, tools, and fasteners	**2**		Due to the technical complexity of a smartphone, many of its parts are not repaired, but rather, replaced. Consequently, the ease of disassembly enables the replacement of parts, and this process constitutes the repair of the smartphone as a whole.
CT 2.1	*Ease of disassembly of parts more prone to substitution (priority parts)*	*1*	• Ordinal scale with four levels per parameter • Zero if the number of steps is more than 16 • Higher when there is a reduced number of steps in disassembly	Assesses the disassembly of battery, display and cameras.
CT 2.2	*Required tools*	*0.5*	• Ordinal scale with four levels per parameter • Zero if parts are not removable • Higher when requiring standard tools • Maximum if no tools are required	
CT 2.3	*Characteristics of fasteners*	*0.5*	• Ordinal scale with three levels per parameter • Zero if not removable and not reusable • 1 point if removable and not reusable • 2 points if removable and reusable	
CT 3	Commitment on the availability of spare parts in the market	**2**		It assesses the availability from and to different target groups (producer, spare parts retailers, repairers, and consumers). This follows the same score structure as CT1.
CT 3.1	*Parts more prone to substitution (priority parts)*	*1*	• Ordinal scale with three levels per parameter • Zero if there is no commitment or if it is of less than 4 years • Maximum when the commitment is 7 or more years	Assesses the availability of spare batteries, displays, cameras, and chargers to different target groups.
CT 3.2	*General parts*	*0.5*	• Ordinal scale with three levels per parameter • Zero if there is no commitment or if it is of less than 4 years • Maximum when the commitment is 7 or more years	
CT 3.3	*Time of delivery of priority spare parts*	*0.3*	• Ordinal scale with three levels per parameter • Zero if the delivery time is more than 10 days • Maximum when the delivery is less than 3 days	Measured in working days.
CT 3.4	*Time of delivery of general spare parts*	*0.2*	• Ordinal scale with three levels per parameter • Zero if the delivery time is more than 10 days • Maximum when the delivery is less than 3 days	Measured in working days.
CT 4	Price of spare parts	**2**	• The score is given based on calculating the ratio of the cost of priority spare parts to the cost of a new product.	
CT 5	Specific criteria	**2**		Set of criteria specific to the product category of smartphones.
CT 5.1	*Information on updates*	*1*	• Binary scale	
CT 5.2	*Type of remote assistance*	*0.5*	• Binary scale, based on information for each target group	Availability to repairers and consumers.

(Continues)

TABLE 2 (Continued)

#	Criteria	Weight factor in the score	Score characteristics	Additional information
CT 5.3	*Type of reset*	*0.5*	• Binary scale, based on information for each target group	Availability of resetting the operating system and firmware for the producer, repairers, and consumers.

TABLE 3 Example of an Index of Repairability (IoR) calculation table in the French legislation for the iPhone 11. *Source*: Indice de réparabilité (2021). Numerical data of Table 3 is available in A_Table_3_data in Supporting Information S1.

Critère	Sous-critère	Note du sous-critère sur 10	Coefficient du sous critère	Note du critère sur 20	Total des notes des critères sur 100
CRITÈRE 1 : DOCUMENTATION	1.1 Durée de disponibilité de la documentation technique et relative aux conseils d'utilisation et d'entretien	6.2	2	12.3	45.9
CRITÈRE 2 : DÉMONTABILITÉ, ACCÈS, OUTILS, FIXATIONS	2.1 Facilité de démontage des pièces de la liste 2	0.8	1	4.3	
	2.2 Outils nécessaires (liste 2)	1.9	0.5		
	2.3 Caractéristiques des fixations entre les pièces de la liste 1 et de la liste 2	5.0	0.5		
CRITÈRE 3 : DISPONIBILITÉ DES PIÈCES DÉTACHÉES	3.1 Durée de disponibilité des pièces de la liste 2	6.5	1	9.3	
	3.2 Durée de disponibilité des pièces de la liste 1	1.3	0.5		
	3.3 Délais de livraison des pièces de la liste 2	6.5	0.3		
	3.4 Délais de livraison des pièces de la liste 1	1.3	0.2		
CRITÈRE 4 : PRIX DES PIÈCES DÉTACHÉES	4. Rapport prix des pièces de la liste 2 sur prix de l'équipement neuf	0	2	0	
CRITÈRE 5 : CRITÈRE SPÉCIFIQUE	5.1 Informations sur la nature des mises à jour	10.0	1	20.0	
	5.2 Assistance à distance sans frais	10.0	0.5		
	5.3 Possibilité de réinitialisation logicielle	10.0	0.5		
				Note de l'indice sur 10	4.6

TABLE 4 The Index of Repairability (IoR) score range and respective repairability levels in iFixit. Adapted from iFixit (2023).

Color	Score (integral number)	Repairability level
Red	1	Not possible without damage
Dark orange	2	Very difficult
Orange	3	Difficult
Light orange	4	Moderate (with major weaknesses)
Yellow	5	Moderate (with few weaknesses)
Yellow-green	6	Moderate (with few strengths)
Green-yellow	7	Moderate (with major strengths)
Light green	8	Good
Green	9	Very good
Dark green	10	Excellent

TABLE 5 Score structure of the Index of Repairability (IoR) in French legislation and iFixit. *Source*: Légifrance (2023); iFixit (2023).

French IoR	iFixit IoR
0–1.9	1
2–3.9	2
	3
4–5.9	4
	5
6–7.9	6
	7
8–10	8
	9
	10

TABLE 6 Scope of iFixit IoR in the French IoR. *Source*: MTE (2023); iFixit (2023).

French IoR		
#	**Criteria**	**iFixit**
CT 1	Documentation and commitment for updates over time	• Partially addressed. Access to documentation provided by the manufacturer is a requirement for scoring 10 points in the iFixit IoR.
CT 2	Disassembly, accessibility, tools, and fasteners	• This criterion is fully addressed in the iFixit IoR. iFixit presents a qualitative assessment that includes the time and complexity of disassembly and reassembly, which are not covered in the French IoR.
CT 3	Commitment on the availability of spare parts in the market	• Not addressed.
CT 4	Price of spare parts	• Not addressed.
CT 5	Specific criteria	• Not addressed.

Regarding CT2 in the French IoR, the iPhone 11 scored a 2.2 and Samsung Galaxy S10 scored a 3.4. The main reason for the difference lies in the ease of disassembly of priority parts (CT2.1) and required tools (CT2.2). The score difference in CT2.1 is justified by the number of steps taken to disassemble parts. As an example, according to iFixit guides, substituting the battery in the iPhone comprises 44 steps against 15 in the Samsung models and 44 in substituting the screen against 24, respectively. In CT2.2, the iPhone scored lower because it requires the use of proprietary tools, while Samsung requires the use of only one basic tool.

To assess the difference in results in the iFixit IoR, we compared those with the overall score in CT2 in the French IoR. iFixit scored the iPhone 11 higher than Samsung S10 because it does not consider only the number of steps for disassembly but also the level of difficulty in the steps in

TABLE 7 The Index of Repairability (IoR) scores of selected smartphones in the French legislation and iFixit. Source: iFixit (2023) and Indice de Repairabilité (2023). Numerical data of Table 7 is available in B_Table_7_data in Supporting Information S1.

Model	Release date	CT 1	CT 2	CT 2.1.	CT 2.2	CT. 2.3.	CT3	CT 3.1.	CT 3.2.	CT 3.3.	CT 3.4.	CT 4	CT 5	CT 5.1.	CT 5.2.	CT 5.3.	French IoR total	iFixit IoR
iPhone 11	Sep 2019	6.2	2.2	0.8	1.9	5	4.7	6.5	1.3	6.5	1.3	0	10	10	10	10	**4.6**	**6**
Samsung Galaxy S10	Mar 2019	1.9	3.4	3.3	3.8	3	4.9	4.7	5	5	5	9.5	9	10	6	10	**5.7**	**3**
Samsung Galaxy S20	Mar 2020	1.9	2.7	1.7	3.8	3.5	4.9	4.7	5	5	5	10	9	10	6	10	**5.7**	**3***
Samsung Galaxy S20 Ultra	Mar 2020	1.9	2.7	1.7	3.8	3.5	4.9	4.7	5	5	5	10	9	10	6	10	**5.7**	**3**
Samsung Galaxy S20+	Mar 2020	1.9	3.5	3.3	3.8	3.5	4.9	4.7	5	5	5	10	9	10	6	10	**5.9**	**3***
Samsung Galaxy S20 FE	Oct 2020	8.8	3.5	3.3	3.8	3.5	8.4	8.7	7.5	9	7.5	10	10	10	10	10	**8.1**	**3***
Fairphone 3+	Sep 2020	8.5	10	10	10	10	7.2	7.9	6.4	6.7	6.7	8	10	10	10	10	**8.7**	**10**

Note: In Table 7, IoR is used as an acronym for "Index of Repairability" and CT# as an abbreviation of "criterion." All CT# scores are indicated on a 0–10 scale. For clarity purposes, the CT2, CT3, and CT5 values are converted into a 0–10 scale after the application of the weight factor defined in the IoR structure. CT# sub-criteria scores are presented without the weight factor. Table 3 provides the original structure of the French IoR.

self-repair. In this respect, Samsung's use of adhesives in internal sub-assemblies is higher than in the iPhone. This leads to increased difficulty due to the constant removal of adhesives and glue, while also increasing the risk of failure in other parts.

One of the main reasons for the overall lower score of the iPhone in the French IoR is the 0 score in CT4, meaning that the price of spare parts is too close to the cost of a new device. If this criterion were fulfilled the same way Samsung did, then the overall score would be 6.5. In addition, Apple provides more information about the repair process of its iPhone 11 than Samsung does for its phones. The result does not disclose whether the information is for professional repairers or if it is meant for end users to repair their phones.

In summary, iFixit scores Samsung phones lower due to their difficulty of disassembly created by their paramount use of adhesives and the iPhone relatively higher because even though its disassembly encompasses a higher number of steps, it is easier to perform. The French IoR scores the S10 as having moderate reparability because of the reduced number of steps in disassembling it, the ratio of the price of spare parts to the price of a new device is low (CT4), the service quality is moderate (CT3), and the software updates and technical assistance (CT5) rated quite highly.

5.2 | Characteristics of excellent repairability

In this sub-section, we assess the causes for excellent repairability in the French IoR by analyzing the Samsung Galaxy S20 FE (8.1) and the Fairphone 3+ (8.7).

The S20 FE is one of four variants Samsung has released under the S20 product family. Each features different screen sizes and minor differences in specifications; however, they all share a similar product architecture. The S20 Ultra was the only variant analyzed by iFixit, who scored it a 3 out of 10. The main difference between the S20 Ultra and the S20 FE is that the S20 Ultra has a glass back cover instead of a plastic one used in the S20 FE, which scored higher in the French IoR.

A further comparison of the results in the French IoR of the S20+ (5.9) and the S20 FE (8.1) in the five criteria revealed that the scores in CT2, CT4, CT5.1, and CT5.3 were the same. This means both models share the same number of steps for disassembly, required tools, and fasteners; the same ratio of the price of spare parts to the price of a new product; and the same information about updates and types of resets. The differences lie in CT1, CT3, and CT5.2. CT1 holds the sharpest difference. In CT1, a high score indicates that most documentation is available for a period of 6 or more years. In CT3.1, the difference in score means the S20 FE variant provides more documentation and/or for a longer period. In CT3.3, the higher score indicates shorter delivery times for spare parts.

When comparing the Samsung Galaxy S20 FE with the Fairphone 3+, the overall difference is rather subtle, only 0.6 points, while both scored 10 out of 10 in CT5. CT1 is similar, with Samsung scoring slightly higher than the Fairphone. Samsung scores better in the assessment of delivery times of spare parts and the ratio of the price of spare parts to the price of a new product. The sharpest difference is observable in CT2, with the Fairphone scoring a combined 10 out of 10 and Samsung models scoring a combined 3.5 out of 10.

Comparing the total result in CT2 with the iFixit IoR score enables further explanation of the ease of disassembly and overall repairability. In iFixit, the Samsung Galaxy S20 FE is not disassembled, but the S20+ shares the same result in CT2 in the French IoR. The battery substitution is classified as having moderate difficulty, encompassing 31 steps, requiring one basic tool as well as the disassembly of complex sub-assemblies and parts. Opening up the smartphone requires a heating device to soften the adhesive, and removing the battery requires a solution to dissolve the glue from the chassis. Removing the display is classified as difficult and includes 36 steps and similar procedures. In contrast, the battery removal of the Fairphone requires two steps and no tools. The Fairphone's display requires nine steps and one basic tool, which is provided with the device.

We tested the four parameters in CT2.1 and concluded that the score of the Samsung S20 FE is due to the positive score in disassembling the front camera (up to six steps) and the rear camera, which takes between 11 and 16 steps. Despite the reduced number of steps, the front camera is glued to its case, which increases the difficulty of the replacement procedure. We conclude that this level of complexity might make the Samsung Galaxy S20 FE amenable for professional repair but not for self-repair due to its extensive use of glue and adhesives.

In contrast, the Fairphone scores high in both IoRs. It features a simple product architecture and disassembly procedures that enable users to repair parts more prone to substitution, even with little or no experience in self-repair. The Samsung Galaxy S20 FE scores high in the French IoR because it provides good service, and the cost of spare parts is low compared to a new device.

6 | DISCUSSION

6.1 | Criteria in the French IoR and overall communication of repairability

We can classify the five criteria in the French IoR into three areas: design for repairability (CT1 and CT2), spare parts (CT3 and CT4), and software/firmware updates (CT5). From this perspective, the weights are as follows: 40% for addressing design for repairability, 40% for spare parts and servicing, and 20% for software and firmware. When compared to the proposed European RSS (Cordella et al., 2019), the French IoR overlaps excluding two criteria, namely, disassembly time, safety, skills, and working environment. When compared to the proposed specific scoring system for smartphones and slate tablets (Spiliotopoulos et al., 2022), the French IoR comprises a different weight approach to the criteria, with a sharp difference in CT2 (20% in the French IoR against 55% in Spiliotopoulos et al., 2022).

For CT1, the need for manufacturers to provide information supporting repairability over a period of time constitutes the basis for a fairer third-party repair market. Furthermore, the French legislation requires that consumers have access to professional repairers who are either authorized by original equipment manufacturers (OEMs) or independent (MTE, 2022, p.17). Manufacturers must indicate preferable repairers but must refer to a national directory in which consumers have access to more than 100,000 independent repairers (ADEME, 2017). Combined with CT3, the availability of spare parts enables the possibility of repairs. When combined with CT2 (the ease of disassembly) and CT4 (the price of spare parts) it supports the affordability of repairs.

A smartphone can be repaired professionally with the support of proper documentation made available by the manufacturer (CT1) and with parts available in the market delivered just in time (CT3). Nonetheless, the possibility of the repair itself is decisively influenced by the ease of disassembly and the type of fastener (CT2).

To illustrate that premise, we build on the comparison between the Samsung Galaxy S20 FE (8.1) and the Fairphone 3+ (8.7) scores in the French IoR. Both phones are in the highest tier of repairability; nonetheless, the respective score in CT2 of 3.5 and 10 states that the Samsung phone encompasses a high number of disassembly steps while the Fairphone has the minimum number of steps required. Challenges in overcoming the use of adhesives in the Samsung phone can lead to permanent damage to other parts. In the case of professional repair, this can lead to a combined higher final cost, which renders repairs inequitable when compared to the cost of a new product, even though CT4 states that the ratio of the cost of spare parts to the cost of a new device is low. In the case of self-repair, the required use of heat to open the back lid for any repair can present an unmanageable barrier for repair or, if attempted, lead to undesirable results. The difference in the score in combined CT2 in these two smartphones indicates that their respective design for disassembly was not at the same level. Nonetheless, the final overall score makes both smartphones similar in terms of perceived repairability for consumers, which might not be the case in practice when considering the illustrative example. Assessing the structure of CT2.1 and CT2.3 alone provides a further explanation for this cause. The single-point difference does not penalize practices that constitute barriers to repair. As an example, a smartphone that uses adhesive tape as a fastener may score the same as one that uses a reusable fastener, such as screws, if the manufacturer supplies new adhesive tape with the spare part. Moreover, scoring the ease of disassembly by measuring the number of steps does not account for the time or difficulty of the procedure. As observed in the results, the iFixit scores take difficulty into consideration. Including disassembly time as an autonomous criterion could improve the differentiation between devices with product architectures that are more prone to disassembly. Such inclusion could follow the principles defined by Cordella et al. (2019, p. 40), Bracquené et al. (2018), and Spiliotopoulos et al. (2022), together with the priority levels studied for smartphones by Flipsen et al. (2019).

Furthermore, the equal weight of all five criteria levels in the French IoR enables manufacturers to compensate for product development decisions that hinder reparability (CT2) with access to information (CT1), lean strategies in service, and distribution (CT3, CT4, and CT5). In our view, this does not contribute to facilitating the product differentiation that the IoR aims to communicate to the consumer. It also suggests that manufacturers do not necessarily have to shift toward product development practices that promote repairability, such as design for disassembly to obtain high scores.

Firmware and software updates are assessed in CT5. This criterion comprises three sub-criteria with nine parameters. According to the French IoR all conditions were assessed binarily, except one. This justifies the relatively high scores that were given for all analyzed smartphone models.

Repair associations have recently communicated that firmware and software updates can hinder hardware repair (Purdy, 2022). According to these associations, manufacturers can remotely control the functionality of a part, thus disabling the function of successful hardware repair (Right to Repair Europe, 2021). This compromises the common practice in independent repairs of reusing original parts from other smartphones or using third-party components. In the end, the ability to conduct repairs on a phone could be a condition issued by the manufacturer rather than a "right" of the consumer. Further research is required to assess firmware and software updates in correlation to hardware repair so that policies can establish guidelines for the level of control manufacturers have in the use of spare parts and so that independent repairs can be performed without being compromised remotely.

6.2 | Potential to promote sustainable production and consumption patterns

The analyzed IoRs differ in nature and scope. Because the iFixit IoR addresses self-repair only, it can be interpreted that its scores paired with the strengths and weaknesses list may inform users more clearly about a phone's repairability in certain cases. Thus, the overall score in the French IoR would not clearly communicate to the consumer if the smartphone is easy to self-repair or easy and affordable to have it professionally repaired. A clearer definition of who the target repairer is can lead to a different structure in the criteria or to multiple outcomes from the same calculation.

Regarding the potential for shifting the production philosophy, the iFixit IoR raises awareness on barriers to repair in a shorter time by communicating it to a high number of users over the internet. This can lead to a ripple effect in the bottom-up approaches led by environmental NGOs

(Right to Repair, 2020). In a legislative context, the structure of the French IoR nudges (Thaler & Sunstein, 2009) manufacturers to change their approach to information and service by, first, providing information that has been secluded from consumers and independent repairers, and that has been one of the main causes of the "right-to-repair" demands. Manufacturers are encouraged to respond to guidelines on what is reasonable repair service regarding the price of spare parts and delivery times. Such conditions may cause the repair market to become more open. Examples of this phenomenon include Samsung's release of repair manuals and Apple's self-service repair initiative.

Even though these may be considered positive signs, the capability of both iFixit IoR and the structure of the French IoR to directly affect the product development of major companies seems outside the scope of such tools.

7 | CONCLUSION

The inclusion of an IoR in legislation represents a response to the "right-to-repair" demands. This study indicates that to score high in the French IoR, major manufacturers have opted to take indirect measures such as lowering the cost of the spare parts, making spare parts available in a shorter time, or providing access to repair instructions (Purdy, 2021) to consumers and/or professional repairers. Direct approaches such as designing for disassembly were not observed and can be the result of the analyzed smartphones being launched in 2019 and 2020 and the introduction of the legislation in 2021. This topic should be further researched in the future to determine if the French IoR can impact the industrial design of smartphones and shift current production philosophies. We consider that the criteria assessing disassembly, accessibility, tools, and fasteners are key to assessing repairability. The weight factor of these criteria in the overall score in the French IoR is 20% and our thought is that it should be higher. If higher than 20%, then manufacturers would have to include direct approaches such as design for disassembly, a reduction in the use of non-reusable fasteners (e.g., hot-melt adhesives) or proprietary tools, which they currently do not do. This indication is supported by Spiliotopoulos et al. (2022) who propose an overall weight of 55% in these criteria.

Furthermore, the inclusion of disassembly time as a parameter correlated with difficulties (e.g., product architectures and joining methods) in assessing priority parts could further differentiate scores. Moreover, differentiating whether the device is amenable for self-repair, original equipment manufacturer repair, or third-party repair could clarify the main drivers behind the scores.

The data collected for this study are retrieved from manufacturers', policymakers', and communities of users' websites. Information regarding iFixit IoR and the French IoR and its sub-criteria are available on dedicated websites, facilitating the comparison of different smartphone models. Nonetheless, free access to manuals from manufacturers is still not possible when considering the perspectives of potential consumers.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in iFixit, Ministère de la Transition enérgétique (MTE), Légifrance and Indice de Réparabilité. These data were derived from the following resources available in the public domain: https://www.legifrance.gouv.fr/download/pdf?id=3EW2asQgntsWrcVjAJncs3m5ifQeOmNVXdsTzHrVmHE=; https://www.indicereparabilite.fr/logo-indice-reparabilite-2/; https://www.ecologie.gouv.fr/sites/default/files/anglais_0.zip; https://www.indicereparabilite.fr/produit/iphone-11-a2221/; https://www.ifixit.com/smartphone-repairability; https://www.ifixit.com/Device/iPhone_11; https://www.indicereparabilite.fr/produit/smartphone-samsung-galaxy-s10/; https://www.ifixit.com/Device/Samsung_Galaxy_S10; https://www.indicereparabilite.fr/produit/smartphone-samsung-galaxy-s20/; https://www.ifixit.com/Device/Galaxy_S20; https://www.indicereparabilite.fr/produit/smartphone-samsung-galaxy-s20-ultra-5g/; https://www.ifixit.com/Device/Samsung_Galaxy_S20_Ultra; https://www.indicereparabilite.fr/produit/smartphone-samsung-galaxy-s205g/; https://www.ifixit.com/Device/Samsung_Galaxy_S20_Plus; https://www.indicereparabilite.fr/produit/smartphone-samsung-galaxy-s20fe; https://www.ifixit.com/Device/Samsung_Galaxy_S20_FE; https://www.indicereparabilite.fr/produit/smartphone-fairphone-fp3/; https://www.ifixit.com/Device/Fairphone_3; https://www.ifixit.com/Device/Samsung_Galaxy_S20_FE https://www.indicereparabilite.fr/produit/smartphone-fairphone-fp3/; https://www.ifixit.com/Device/Fairphone_3

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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