

ELLEN  
MACARTHUR  
FOUNDATION

**CIRCULAR  
CONSUMER  
ELECTRONICS:**  
AN INITIAL  
EXPLORATION



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This paper provides reflections on what a circular economy approach could look like for the consumer electronics industry. Built on insights from over 40 interviews with leading companies and researchers, the work is based on research supported by Google and undertaken by the Ellen MacArthur Foundation in 2017. The paper focuses on smartphones, laptops, tablets, and smart home devices. It represents a first attempt at a vision for how electronics could fit within a circular economy, and actions by the industry to accelerate the transition.

# CIRCULAR CONSUMER ELECTRONICS: AN INITIAL EXPLORATION

*“It’s a cell phone, it’s a music player, it’s a camera, it’s a Web-enabled device, and much more. Ask yourself if you really need all that high-tech bling.”*

**NPR ON THE RELEASE OF THE IPHONE JUNE 29, 2007<sup>1</sup>**

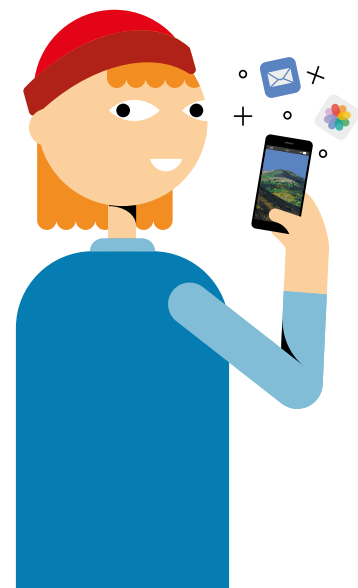
In a relatively short space of time, electronic products have become an essential part of daily life. They are changing the way we work, how we spend our leisure time, and even how we relate to each other. We depend on, and even cherish, these items and the utility they offer. However, most of these devices are still treated as if they are disposable. If we want to enjoy the benefits of technological innovation and access to the services that electronic devices bring, we need to create an electronics system that works.

We’re increasingly surrounded by ever more complex products, from smartphones and computers to entertainment equipment and wearable devices. Even though these items are often made of durable materials such as plastics and metals, they are used for a relatively short period of time before they are no longer considered valuable or useful. Current disposal practices mean much of the energy, resources and value embodied in electronic products is lost, generating vast amounts of waste in the process.

Significant opportunities exist in the transition away from this take, make and dispose, linear model, to one based on the principles of a circular economy. A circular economy is an approach that entails gradually decoupling economic activity from the consumption of finite resources, and designing waste out of the system.

How can we apply the principles of the circular economy to change the way we design, make and use electronics products?

The answer will call for creativity and innovation in areas such as design, business models and reverse logistics.



1 NPR 2007. Seven things to consider before buying an Iphone. Accessed from <https://www.npr.org/templates/story/story.php?storyId=11449714>

Rethinking the design of products is critical to enabling the economic reuse of assets, as well as their components and materials. However, if users continue to landfill their products after the first use, or simply store them in a closet in perpetuity, the impact of better design is limited. Therefore, adopting new business models and deploying effective reverse cycles is instrumental to realising greater product circularity.<sup>2</sup>

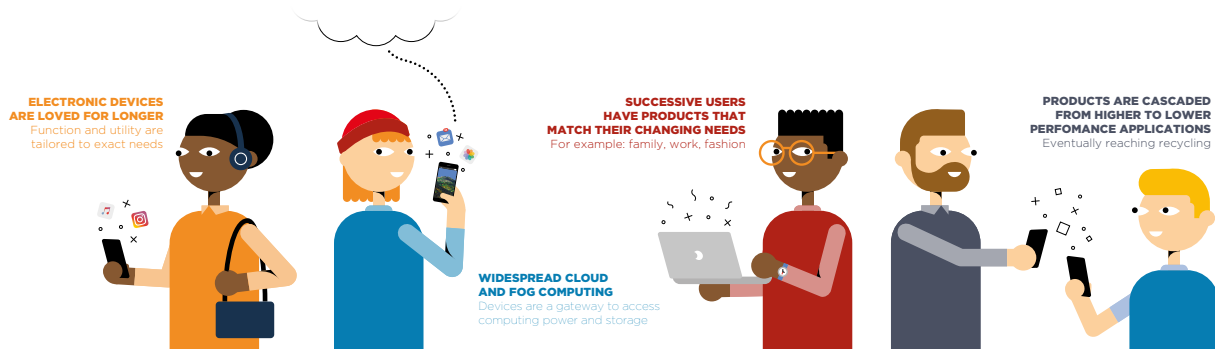
What follows are reflections on what a circular economy approach could look like for the consumer electronics industry. In this paper we have focused on smartphones, laptops, tablets, and smart home devices. Built on insights from over 40 interviews with leading companies and researchers, this represents a first attempt at a vision for how electronics could fit within a circular economy, and the actions by the industry to accelerate the transition.<sup>3</sup>

## VISION FOR CIRCULAR CONSUMER ELECTRONICS

In our vision of a circular economy, consumer electronic products are loved for longer.<sup>4</sup> They are kept in use for as long as possible, either by the original user, or flowing to new users who will find new value and utility in them. Eventually, devices end up in the hands of specialists, who will professionally refurbish products, reuse or remanufacture the valuable components inside, and separate and recycle materials.

With the growing role of cloud computing, electronic products simply act as a gateway to our data, applications and entertainment. This allows computing power and storage to be optimised. The demand for greater and greater storage capacity and computing power is a thing of the past, as the information we need is not stored on the device itself and processing can increasingly happen remotely, keeping earlier models and components in use for longer. This also means that users are more open to letting go of their devices or using products that are not brand new, as long as they have access to their data.

In this circular system, users can quickly find new products that match their lifestyle and changing needs around work, fashion, family or finances.



- 2 Innovative business models have not been considered in this study.
- 3 The cascading of products to emerging economies has not been considered in this study due to the complexity of the issue.
- 4 Products can be designed to stimulate attachment and emotional durability (e.g. Mugge 2017, A consumer's perspective on the circular economy; Thorsteinsson and Page 2014, User attachment to smartphones and design guidelines), and users are increasingly attached to their devices - [The Atlantic, 2017](#).

We have identified four ambitions required to achieve this vision:

- **Electronic devices are loved for longer, by one user or by many:** the distinction between new and secondhand makes little sense when the focus is on functionality, and devices contain new, used and remanufactured components.
- **Devices are a gateway to the cloud:** distributed computing has the potential to increase product longevity by allowing for more flexibility and adaptability in computing power and memory allocation, with the potential to reduce structural waste.
- **Customers get the service that's right for them:** products and components are kept in use; circulated between different categories of users for as long as possible.<sup>5</sup> This way, the residual utility and value of a product are matched to the appropriate needs and budgets of users.
- **Products and components are cascaded:** to get maximum benefit from energy and resources, electronic items move from high-end consumer electronics to lower performance applications. They eventually reach recycling processes, where all materials are recovered and reused in the system.

## THE CHALLENGE AND THE OPPORTUNITY

The electronic waste problem is colossal, and it's growing. In 2016 alone, 44.7 million tonnes of e-waste were generated globally, of which 435 thousand tonnes were mobile phones,<sup>6</sup> representing more than the mass of the Empire State Building.<sup>7</sup> Just 20% of e-waste is documented to be collected and recycled under appropriate conditions, while the remaining 80% is either thrown into the residual waste stream or dumped, traded or treated in substandard conditions.<sup>8</sup>

The consequences of this linear electronics system pose environmental and health impacts both at the production and disposal ends. Vast amounts of energy and hazardous substances are required in the mining and manufacturing of products, and the demand for resources has been linked to dangerous working conditions.<sup>9,10</sup> Disposal and recycling of electronics can expose people and the environment to toxic chemicals when used products are not treated in formal recycling centres.<sup>11</sup>

5 The categories of value users include: 'cutting edge', 'function focused' - different kinds of needs, from storage and computing capacity to camera definition - and 'emerging users'.

6 Baldé, C. P., Forti, V., Gray, V., Kuehr, R., Stegmann, P. 2017. The Global E-waste Monitor 2017.

7 Empire State Building has a mass of 365,000 tonnes. Empire State Realty Trust, [https://www.esbnyc.com/sites/default/files/esb\\_fact\\_sheet\\_4\\_9\\_14\\_4.pdf](https://www.esbnyc.com/sites/default/files/esb_fact_sheet_4_9_14_4.pdf). Accessed January 2017.

8 Baldé, C. P., Forti, V., Gray, V., Kuehr, R., Stegmann, P. 2017. The Global E-waste Monitor 2017.

9 Financial Times, 2017. Amnesty warns on use of child labour in cobalt mining. <https://www.ft.com/content/bec64762-c923-11e7-ab18-7a9fb7d6163e>

10 The Guardian, 2014. Rare earth mining in China: the bleak social and environmental costs, <https://www.theguardian.com/sustainable-business/rare-earth-mining-china-social-environmental-costs>

11 Perkins, D.N., Brune Drisse, M.N., Nxele, T., Sly, P.D. E-Waste: A Global Hazard. *Annals of Global Health*, Volume 80, Issue 4, 2014, Pages 286-295, ISSN 2214-9996, <https://doi.org/10.1016/j.aogh.2014.10.001>.

At the same time, the economic opportunity is significant. Taking smartphones as an example, almost 1.5 billion are shipped every year,<sup>12</sup> with each unit containing components worth over USD 100.<sup>13,14</sup> This represents a potential USD 150 billion of value that enters the market each year. This value should remain in the system.<sup>15,16</sup> Even if the materials present in smartphones that were recovered through recycling – the least valuable loop of a circular economy – they could be worth up to USD 11.5 billion.<sup>17</sup>

The need to rethink the system is clear, but solutions so far have been limited. The circular economy presents a vision and a workable path forwards.

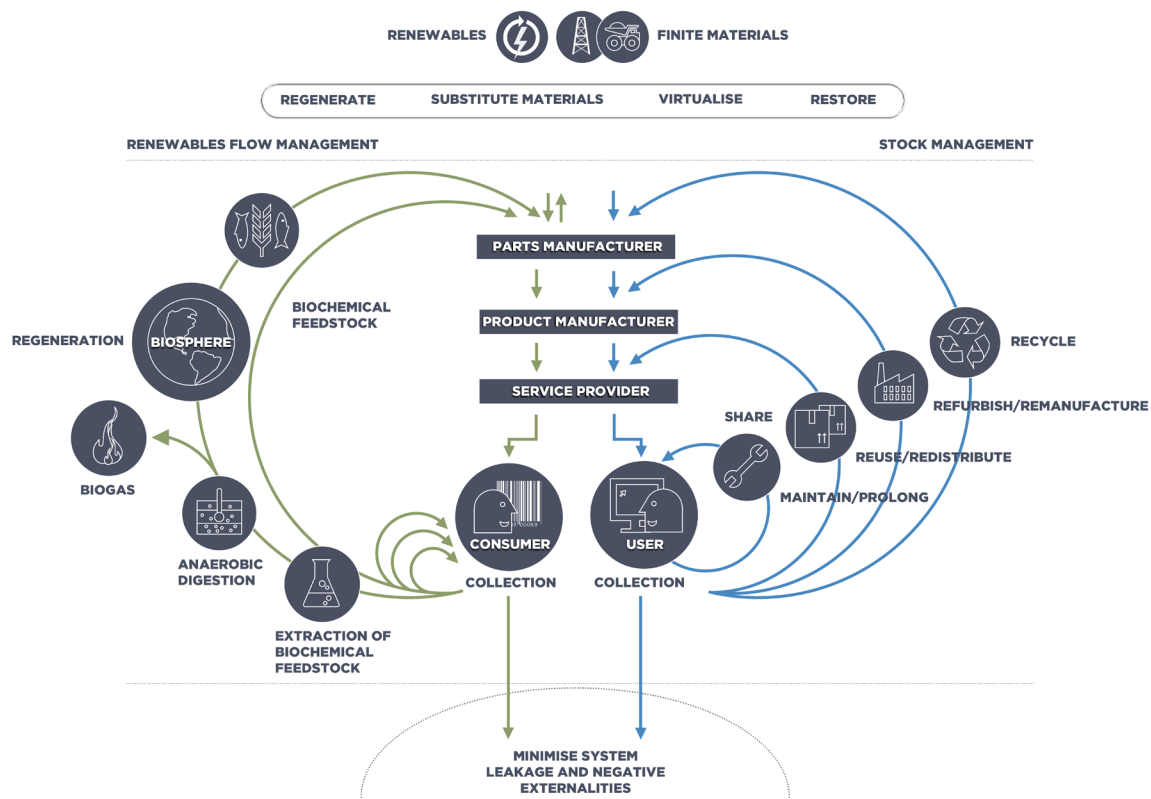
## THE ROAD TO CIRCULARITY: HOW FAR ALONG IS THE INDUSTRY?

Different strategies can be taken to move the electronics industry away from the take, make and dispose model. Many of these strategies can be clustered according to the different ‘loops’ of a circular economy (Figure 1), and some are more widespread and sophisticated than others.

In a circular economy, more value is created in the ‘inner loops’, as the value and utility in the products and components is preserved. Although the level of component reuse across the industry today is largely unexplored, there are concrete examples of companies doing this, opening the door for value to be cascaded, as electronic items are reused in multiple different applications.

Recycling is still part of the picture, and it is vital that constituent materials can be separated and processed when products and components are no longer used. There is increasing momentum in technologies that enable higher yields and quality of material recovery in these ‘outer loops’.

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- 12 IDC, 2017. Data corresponding to period from Q4 2016 to Q3 2017. <https://www.idc.com/getdoc.jsp?containerId=prUS42268917>; <https://www.idc.com/getdoc.jsp?containerId=prUS42507917>; <https://www.idc.com/getdoc.jsp?containerId=prUS42935817>; <https://www.idc.com/getdoc.jsp?containerId=prUS43193517>. Accessed January, 2018
- 13 And up to more than USD 300 - HIS Markit, 2017. <http://news.ihsmarket.com/press-release/technology/iphone-x-costs-apple-370-materials-ihs-markit-teardown-reveals>. Accessed November, 2017.
- 14 Techwalls, 2017. <https://www.techwalls.com/production-costs-of-smartphones/>. Accessed January 2018.
- 15 In a circular economy, products, components and materials are kept at their highest utility at all times. In our current system, not all the value in the components in use can be recovered, and the value usually rapidly decreases with time. Circular design would help products, components and materials to keep their value.
- 16 This value is almost ten times higher than the value of the 2016 global used smartphone market of USD 17 billion - Deloitte 2016. Used smartphones: the USD 17 billion market you may never have heard of.
- 17 Baldé, C. P., Forti, V., Gray, V., Kuehr, R., Stegmann, P. 2017. The Global E-waste Monitor 2017. Source value expressed in Euros (€9.4 billion) - conversion rate used: 1.23 dollars to 1 euro.

**Figure 1:** Circular economy systems diagram

## KEEPING PRODUCTS IN USE FOR LONGER

### DESIGN STRATEGIES

When it comes to keeping entire products in use, there are two main strategies currently being taken by companies:<sup>18</sup>

- repair, refurbishment and upgrade by users (e.g. Fairphone via modularity with spare parts and manuals available online)
- repair/refurbishment by technicians (e.g. iPhone)

Companies may follow intermediate strategies, where parts of the product or certain components can be repaired by users who have appropriate knowledge and tools. Whether undertaken by users or by professional technicians, both models have the potential to support a more circular use of resources, as the overall product longevity may be extended by the same amount, under the right conditions.<sup>19</sup> The difference lies in the relationship between the device and the user, which is often significantly more influential than the durability of the item itself.

<sup>18</sup> Both strategies include a certain degree of ease of disassembly, since a certain degree of reparability and design for recycling is necessary.

<sup>19</sup> Depending on pace of technological innovation, software compatibility, upgradability of devices, emotional durability.

Although a degree of repairability and ease of disassembly are necessary in both strategies, the ideal scenario of full repairability by user is not the only way forward.<sup>20</sup> Ultimately, what matters is that the chosen strategy leads to products, components and materials kept at their maximum utility for as long as possible. More information on circular design strategies can be found in the Circular Strategies<sup>21</sup> Framework and Circular Design Guide.<sup>22</sup>

## **USER PERCEPTION**

Most discussions around the topic of user perception has been centred on people's openness to used and refurbished products. Research shows that up to 50% of users would be willing to have used or refurbished products under the right conditions.<sup>23,24</sup> Some, such as 'techies' or 'fashion oriented' users, may not be interested in them under any circumstances, but these groups only represent part of the market.<sup>25</sup>

In today's electronics market, there are multiple factors deterring users from refurbished and used devices. For some, it will be the assumption of inferior performance and financial risk should an item malfunction. Others only consider new devices as they want to stay up to date with continual technological change, and associate used products with being 'left behind'. On the supply side, data safety concerns can lead people to store their devices in their homes indefinitely. Many of these issues related to used products can be addressed through guarantees and transparency in the secondhand market, which offer added assurance and confidence for customers.

To investigate changing user practices, consumer electronics businesses could target the so-called 'leading edge' users. This segment of the market acts as leaders, often adopting behaviours or practices that the rest of the market will follow over time. In addition, leading edge users look out for the next big innovation, and this mindset could open the way for more 'circular' products and business models.<sup>26</sup>

User perception could be seen as an obstacle to establishing the principles of a circular economy in the electronics industry. However, manufacturers, retailers and brands have the chance to harness user perception and use it to their advantage to obtain the maximum utility from their products.

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20 Apart from the technical difficulties that this demands, some users may consider this too risky or lack sufficient skills.

21 Ellen MacArthur Foundation, 2017. Article published in Circulate. <http://circulatenews.org/2017/12/circular-electronic-product-must-three-features/>

22 EMF and IDEO, 2017. <https://www.circulardesignguide.com/>

23 WRAP 2017. Switched on to value: Powering business change

24 Main barriers for users choosing refurbished products are lack of availability, misconception of refurbished concept, and sense of risk - Mugge, R., Jockin, B., Bocken, N. (2017) How to sell refurbished smartphones? An investigation of different customer groups and appropriate incentives, Journal of Cleaner Production, Volume 147

25 Detailed description of these user profiles can be found in Mugge, R., Jockin, B., Bocken, N. (2017) How to sell refurbished smartphones? An investigation of different customer groups and appropriate incentives, Journal of Cleaner Production, Volume 147.

26 "The changing relationship between people and goods," SITRA 2017.



## REFURBISHMENT

Investments in refurbishment technologies are increasing the value and quantity of refurbished and remanufactured electronic devices that are available. This makes used items more attractive to customers, and also makes it possible for businesses and larger organisations to consider using them at scale.

The latest refurbishment methods allow these products to compete with new products, in terms of function and appearance. Some devices, for example modems, are being reused in an average of five households during their lifetime.<sup>27</sup>

Increasing automation is opening up new possibilities and helping keep products in use for longer. Businesses are now able to automate the assessment of devices, and the implementation of industrial scale, batch refurbishing of parts is reducing costs. However, there is still a considerable difference between the efficiency and sophistication of the manufacturing of new products, compared to the treatment of used assets. Without further exploration, refurbishment remains a largely manual process, and the amount of time that can be invested in each device is limited.

## CLOUD COMPUTING

Cloud computing can play an important role in prolonging the use of electronic devices. By dematerialising and transferring capabilities from consumer hardware to the cloud, the pace of hardware obsolescence can be reduced. Additionally, it leads to a more optimal use of storage space and computing power, since the operators of cloud services will make better use of resources than individuals' hardware. Connection speed is often quoted as an obstacle to the wider adoption of cloud computing, but there are instances of speed-dependent applications being successfully used, for example in gaming.<sup>28</sup>

Migrating to the cloud unlocks several circular economy opportunities. For example, it has been proposed that users are more attached to their data than to the devices themselves,<sup>29</sup> so in addition to reducing the pace of hardware obsolescence, it could also reduce the sense of risk users may have from used or refurbished devices.

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27 Teleplan, 2016. Sven Boddington and Xavier Hubert. White paper: 'The Circular Economy is fundamentally altering the definition of "new equipment". So what can be done to accelerate the change of attitude in the market towards so-called "used electronics equipment"?'

28 High performance remote computing is already applied in gaming, for example: <https://www.nvidia.co.uk/shield/games/>.

29 Wilson et al. 2017. The hibernating mobile phone: Dead storage as a barrier to efficient electronic waste recovery.

## COMPONENT AND MATERIAL RECOVERY

### REUSE OF COMPONENTS

Components are being reused in the current system, although the degree to which this is happening is not clear. Components are both reused by companies in official refurbishment operations, and are also exchanged by users on other platforms.<sup>30</sup>

Cascading of components is happening to some extent, with parts of some electronic products used in other applications, and some companies producing apps and updates that add functionality to equipment that could otherwise be seen as obsolete.<sup>31</sup> The current growth of the Internet of Things<sup>32</sup> is driving the need for electronic components. Reusing basic components, such as screens, batteries, sensors, hard drives, and chips, from higher performance applications to lower ones could help to displace the consumption of new primary resources, and keep those components in use for longer.<sup>33</sup>

However, lack of standardisation of components and the fast pace of technological change are two factors that hinder reuse. A better understanding of the current limits to the reuse of components would allow for more constructive discussions.

### MATERIAL RECOVERY

Recycling technologies are continuously developing. They promise to increase yields and lower the environmental impacts of recycling methods. Examples of these are electrochemical processes,<sup>34</sup> hydrometallurgy,<sup>35</sup> and more traditional pyrometallurgy,<sup>36</sup> which apply to metals in electronics. In terms of plastics, it is now possible to create recycled polymers that are of similar quality to new, providing a number of considerations are taken into account. The design of products and components must allow for the identification and separation of materials, which is frustrated if different materials are fused together, for example. Strict collection standards must be kept to ensure different material streams are kept separate.<sup>37</sup> Ensuring that plastics are not contaminated by banned or toxic substances can enable materials to be kept in use for longer. Fortunately, technologies that allow the removal of contaminants are now being developed and implemented.<sup>38</sup>

Increasing yields and quality of materials, when combined with deliberate design for recycling, strengthen the economic case for the recovery of consumer electronics after use.

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30 For example Ebay, GumTree, etc.

31 For example Galaxy Upcycling: <https://galaxyupcycling.github.io>

32 Number of connected devices is expected to reach over 20 billion in 2020 (Gartner, 2015). <https://www.gartner.com/newsroom/id/3165317>. Accessed January 29, 2018.

33 Used smartphones are starting to be used as smart home devices (e.g. [Digital Trends, 2017](#))

34 For example, Enviroleach Technologies <https://enviroleach.com/>

35 For example, Ronin8 <http://ronin8.com/>

36 For example, Umicore <http://www.umicore.com/>

37 As per conversation with expert recycler in Brazil.

38 For example, Coolrec.

## PRODUCTS IN THE RIGHT PLACE

### LOGISTICS

Logistics is both a key challenge<sup>39</sup> and an enabler for circularity in the electronics sector. There are few examples of companies that have adopted product take-back as a central part of their business model,<sup>40,41</sup> and while evidence in favour of more sophisticated reverse logistics is not conclusive, this piece of the value chain plays a vital role in the circular economy, and warrants further exploration. In other products that are outside the scope of this paper, such as printer and toner cartridges, there are cases of successful collection programmes. Lexmark, for example, recovers half of its cartridges for reuse or recycling, and HP collected 17,000 tonnes of ink and toner cartridges in 2016.<sup>42,43</sup>

Three issues often overlap when discussing logistics: incentives for the user to return their products to the manufacturer, the reverse logistics processes themselves, and regulatory complexity. The first of these relates to issues ranging from fears about data safety to a lack of understanding of the value in used devices and how to return them. Secondly, logistics processes are often hindered by geographical distribution and difficulties in generating a stable and predictable flow of returned products. Finally, regulations have been traditionally focused on controlling e-waste flows instead of enabling a circular economy, so transporting items that have value but are classified as 'waste' can be met with legislative barriers.

Although reverse logistics do represent a challenge in the current system, we have not encountered evidence suggesting it is a barrier that cannot be overcome. Additionally, disentangling these different aspects can help explore how to enhance them.

### INFORMATION

Information is central to obtaining the most utility from devices. It can help both manufacturers and users see the true value of these devices, including their whereabouts, condition, and recovery potential. This information can enable products to be repaired or refurbished in a more time-effective manner. Material passports are an example of efforts to keep information about the material composition and design together with products throughout their use, to allow for the highest value retention and recovery further down the line.<sup>44</sup> Information sharing is often a very sensitive issue, but understanding precisely what information is needed and developing appropriate channels may reduce the associated sense of risk.

39 One of our interviewees reported that it represented up to two-thirds of the total costs of producing recycled material.

40 Although not central to their business models, many companies are implementing take-back schemes, for example: <https://www.pcmag.com/feature/315832/the-top-laptop-trade-in-programs>

41 Examples of successful pilots in action are Samsung and Argos in REBus, 2017. Moving towards a circular economy. <http://www.rebus.eu.com/wp-content/uploads/2017/12/REBus-project-Moving-to-a-circular-economy.pdf>

42 Lexmark, 2018. [https://www.lexmark.com/en\\_gb/products/supplies-and-accessories/lexmark-collection-and-recycling-program.html](https://www.lexmark.com/en_gb/products/supplies-and-accessories/lexmark-collection-and-recycling-program.html). Accessed, 5 January 2018.

43 HP, 2018, <http://www8.hp.com/uk/en/hp-information/environment/recycling-reuse.html>

44 For example Maersk: <https://www.ellenmacarthurfoundation.org/case-studies/using-product-passports-to-improve-the-recovery-an>

## BUSINESS MODELS

Capturing residual value or utility is central to reaching a circular economy for electronics. Business models are adapting, and access models, in which the manufacturer retains ownership and responsibility for the product, have led to high rates of recovery and reuse in products such as modems. This is now being demonstrated elsewhere, as shown by the number of cases that prioritise access over ownership for both smartphones<sup>45</sup> and laptops.<sup>46</sup>

Adapting business models can help capture greater value in electronic products, while developing a new type of relationship with customers, and keeping valuable resources in use for longer.

## THE ROLE OF RESIDUAL VALUE

### HOW EVERYTHING AFFECTS AND IS AFFECTED BY VALUE

Residual value is determined by how much functional value a product retains over time and whether users perceive this. All the factors discussed above, such as the design of the device, refurbishment technology, speed of technological development, logistics, user perception, and quantity of products available, can affect the utility and value of used devices. Understanding residual value highlights the opportunity to apply a systemic approach to change, and to reinvent our relationship with consumer electronics

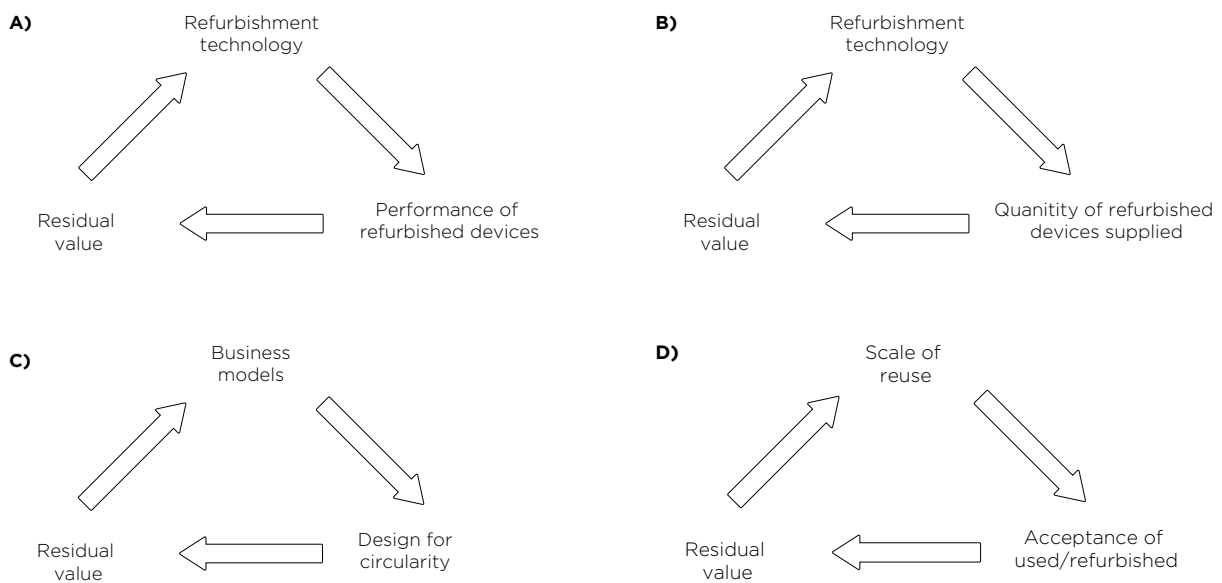
Figure 2 shows how some of the factors mentioned above are interconnected. For example, the development of refurbishment technology improves the performance of refurbished devices, which increases the residual value of used devices. As the performance of refurbished devices improves, they are worth more, and refurbishers can increase their profits and invest in even more sophisticated technology and processes (Fig. 2a).

Similarly, with better refurbishment technology, devices that could not previously be refurbished can be treated to a level at which they can compete new devices. This allows refurbishers to access a larger pool of resources for the refurbishment process, increasing production volumes. This could help to attract clients that need large volumes of assets, such as businesses, whilst at the same time increasing the value of used devices, irrespective of their state (Fig. 2b).

Another example is the reinforcing cycle between business models, design for circularity and value. Incentives shift as companies modify their business models to capture the value of circularity. If product design is reprioritised to keep products and materials in use, the more value those assets will retain (Fig. 2c). Finally, as reused and refurbished products become more common, and people see others using them, their acceptance will increase.

45 Deloitte 2017. Global Mobile Survey 2017: UK cut

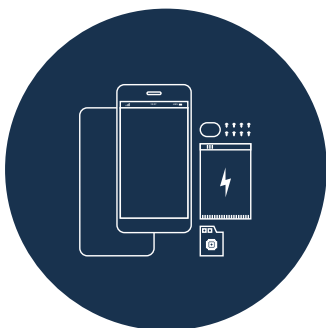
46 For example, Dell PC as a service: <http://www.dell.com/en-us/work/learn/pc-as-a-service>

**Figure 2:** Reinforcing cycles affecting the residual value of consumer electronics.

The four loops in Figure 2 have the potential to become reinforcing feedback loops, tipping the system towards a more circular use of resources. Achieving this will require a range of efforts, from technological innovation to cross value chain collaboration. The following section identifies industry actions that would help accelerate the transition towards a circular economy for consumer electronics.

## FIVE INDUSTRY ACTIONS TO ACCELERATE THE TRANSITION TOWARDS A CIRCULAR ECONOMY

The development of a circular economy is poised to change the way that we design, make, and use consumer electronic products. We have identified five actions that the industry can take to accelerate this transition, whilst maximising economic, social and environmental benefits.



**1. Design for circularity: select a circular design strategy that fits the business model and the wider system in which the device operates. These strategies can range from ‘designing for durability’ to ‘designing for adaptability and repairability’, but they will focus on preserving value in both the inner and outer loops of the technical materials cycle, such as increasing the ease of partial disassembly, and only including materials fit for a circular economy.<sup>47</sup>**

*Analysis: There is no silver bullet in terms of design for circularity. What will determine the success of the design is whether it fits within the broader system in which the*

device operates. However, partial disassembly is required under all scenarios, since some components, such as batteries, rarely last the full lifetime of the device and need to be easily removed for remanufacturing or recycling



**2. Give added purpose to cloud migration: as more computing happens through the cloud,<sup>48</sup> hardware capabilities become less important than connectivity. Combined with longer operating system stability, this has the potential to reduce the pace of hardware obsolescence.**

*Analysis: Cloud and fog<sup>49</sup> computing are on the rise.<sup>50</sup> This has the potential to both reduce computing demands for hardware and also to change our relationship with physical products. For example, user data stored in the cloud eases the switch between devices, since arguably people are more attached to the data in their devices than to the products themselves,<sup>51</sup> further reinforcing the access instead of ownership paradigm. Additionally, device performance tracking can recall devices for repairs or refurbishment at appropriate times.*



**3. Products match changing needs: products are circulated between users with different and changing needs, aided by real-time product performance communication which notifies and guides the user when components or products need to be changed. Big data and advanced analytics can vastly increase the effectiveness of this matching exercise and help predict reverse logistics demands.**

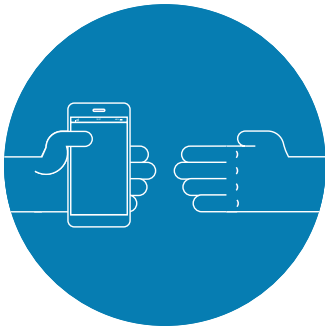
*Analysis: hardware components can be monitored to detect how optimally the device is being used, and whether it is no longer able to supply the desired functions, while offering local solutions for the user to maintain or recover the maximum value from the device.*

48 McKinsey 2016. IT as a service: from build to consume.

49 "Fog computing is a term created by Cisco that refers to extending cloud computing to the edge of an enterprise's network. Also known as Edge Computing or fogging, fog computing facilitates the operation of compute, storage and networking services between end devices and cloud computing data centers." Source: Webopedia: <https://www.webopedia.com/TERM/F/fog-computing.html>. Accessed January 30, 2018.

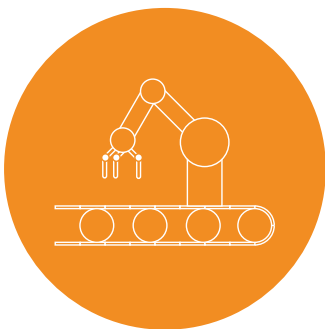
50 50 billion 'things' are expected to be connected by the year 2020. Source: Cisco, 2015. Fog Computing and the Internet of Things: Extend the Cloud to Where the Things Are. White Paper. [https://www.cisco.com/c/dam/en\\_us/solutions/trends/iot/docs/computing-overview.pdf](https://www.cisco.com/c/dam/en_us/solutions/trends/iot/docs/computing-overview.pdf)

51 Wilson et al. 2017. The hibernating mobile phone: Dead storage as a barrier to efficient electronic waste recovery.



**4. Increase reuse market efficiency: the secondhand market builds trust by improving transparency of pricing, product specifications, condition, and traceability.<sup>52,53</sup> This can be achieved by supporting users in reselling their devices by providing them with price estimates, product information, specifications and condition, and certified refurbishment and remanufacturing activities.**

*Analysis: the performance and price risk of used and refurbished devices are two of the main user perception barriers. Supporting users in buying and selling devices by building trust and transparency would help users see the real value in used and refurbished devices.*



**5. Increase automation in disassembly and refurbishment processes: improved automated processes can increase the number of products that can be treated and reduce the time they require to be treated. Increased quantity and better quality of material yields will strengthen the economic case for recycling.**

*Analysis: the complexity of electronic devices coupled with the relative lack of investment in disassembly, refurbishment and recycling mean that it is often a labour intensive, manual process. Developing cost effective methods for disassembly and recycling, that do not compromise the quality of materials produced, would strengthen the economic case by both increasing the quantity of devices that can be treated, as well as the yields and value of the resulting products and materials. Leveraging robotics and machine learning technologies, combined with sharing relevant information, could hold the key.*

## CLOSING CONSIDERATIONS

Transitioning towards a circular economy of consumer electronics has the potential to benefit the economy, society and the environment. In this investigation we have tried to outline a vision of what such a system would look like and identified actions that will take us there.

There are still many questions left unanswered. For example, how can artificial intelligence, big data and machine learning best be used to enable the circular economy? How should

52 Several companies and platforms are making headway on this front, for example: [Sage - BlueBook](#), [Swappa](#), [Apple](#), and [Dell](#). However, more could be done to dispel the perceived financial and performance risks (Mugge, 2017; Wang, 2013)

53 Trade in programmes are another example.

integration of device functions be included in circularity considerations? Can blockchain improve traceability of products and components and help improve user perception of used devices? Regarding business models, how will they best adapt to capture the value added by the circular economy, and how will these changes affect third parties?

The transition to a circular economy presents clear opportunities for the consumer electronics industry, but there are still challenges to overcome. It is now time to decide how the new system will look and function, and exactly which steps we need to take to get there.

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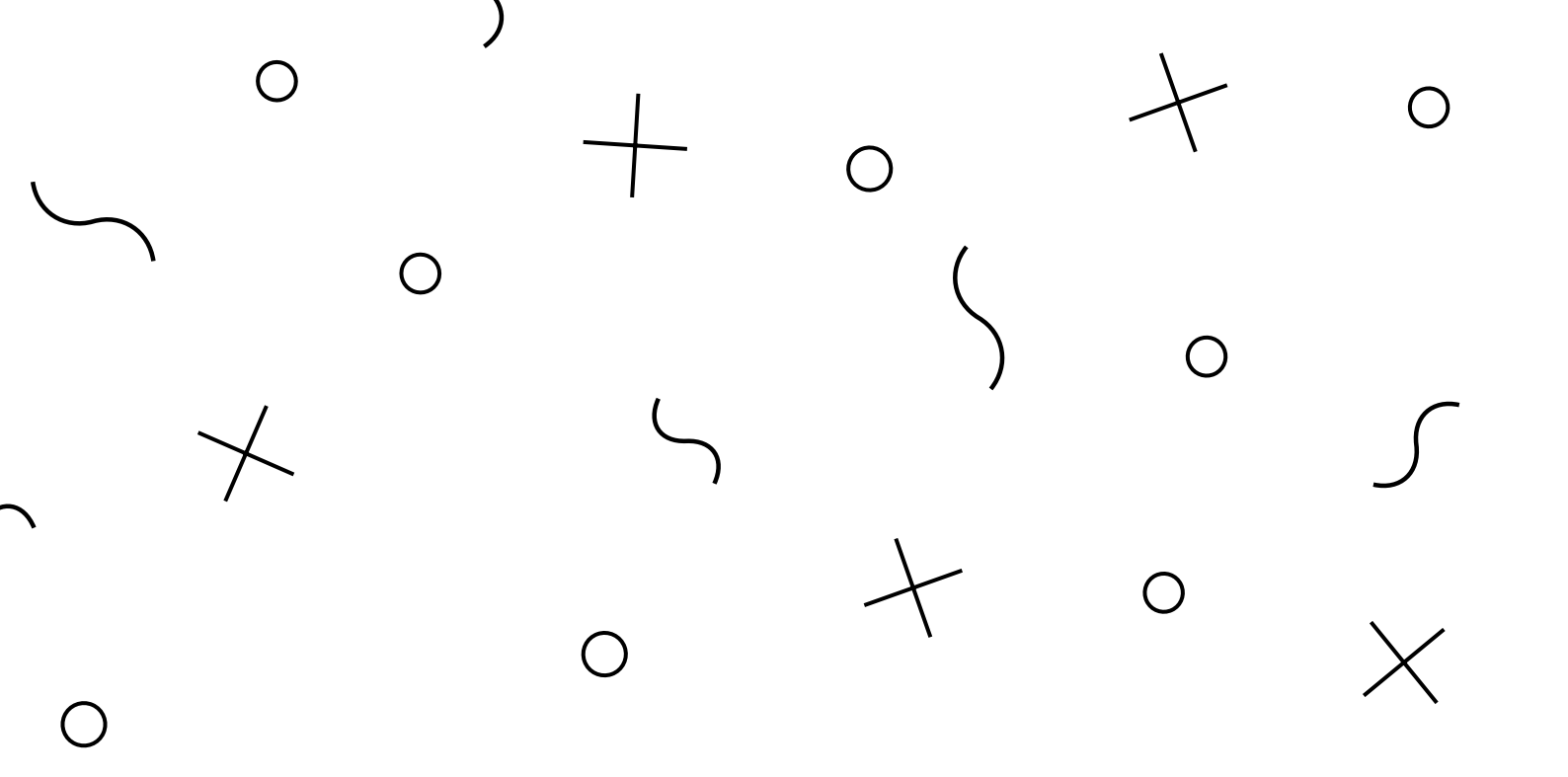
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