Devices as a Commons: limits to premature recycling

David Franquesa
Universitat Politècnica de Catalunya
Barcelona
d.franquesa@ereuse.org

Leandro Navarro
Universitat Politècnica de Catalunya
Barcelona
leandro.navarro@upc.edu

ABSTRACT

Owners of electronic devices typically decide whether or when they become e-waste or are still reusable. For a device in a commons model, where devices are collectively owned and managed, we propose restricting this individual choice in favour of the collective choice. This is achieved through external and internal organisational and governance instruments for a commons-based cooperative platform that has developed over the last three years, handling more than 700 computers. As part of that governance, we present the circular product licence, where the ownership of a device is not linked to the first user but resides in a community or organisation responsible for safeguarding its reuse, ensuring that a pool of devices, as a commons, will have a maximised lifetime through multiple reuse cycles. Devices will only be recycled when there is no longer a demand or reuse potential. We describe an algorithm to estimate the use value of the devices, such as laptops and desktops. When this value is too low or has no demand, the community in custody obtains recycling permission; otherwise, a cycle of reuse begins. These open-source tools that are part of the eReuse.org platform bring automation, cost reduction, traceability, and auditability to all the steps in the lifetime of any device included in the commons, across manufacturing, use, reuse, repair, refurbishment, and final recycling.

KEYWORDS

Circular economy, digital devices, licences, use-value, algorithms, platform cooperativism

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1 INTRODUCTION

We often wonder whether a mobile phone or a laptop that we no longer use can still be useful. Sometimes, we offer them to relatives, sell them, or donate them to social entities that put them to use. However, reuse is not easy, and we often give up. In the best case, it ends up at a collection point for recycling.

Electronic waste, or e-waste, refers to all electrical and electronic equipment (EEE) and the parts that have been discarded by the owner as waste without the intent for reuse [2, 4]. According to the EC (Nov.2008) [5], 'waste means any substance or object which the holder discards or intends or is required to discard', which means the decision of becoming waste is determined by the owner. If the owner decides this and sends it to be recycled, the good ceases to be a product and becomes waste. Once it is considered waste, only an authorised waste management entity can prepare it for reuse and convert it back into a product.

The amount of obsolete electronic equipment is further driven by relatively short replacement cycles. Since technology changes quickly, many users change devices, such as their mobile phone, regularly and often before the devices break. This and other factors generated a volume of 44.7 million metric tonnes of e-waste in 2016. Only 20% (8.9 Mt) of e-waste is documented to be collected, and the fate of 76% (34.1 Mt) of e-waste is unknown; it is likely dumped, traded, or recycled under inferior conditions [2]. Dumping in landfills leads to toxins leaking into the environment, and incineration leads to emissions in the air. These disposal scenarios exist in both developed and developing countries.

The challenge we address is the implementation of a circular economy [14] from the perspective of extending the lifetime (or use) of electronic/digital devices as much as possible by repairing, updating, refurbishing, and reusing them. Breaking the barriers to circularity [9] requires efficient tools and services to optimise each step and ensure the traceability of devices managed as a commons resource system [8]. The aim is to only recycle devices with low use value and no demand for reuse. In that case, we ensure proper recycling in a traceable manner. By use value, we refer to the usefulness of a commodity, in comparison to the exchange value by which the commodity compares an item to other objects on the market.

This paper builds on our experience in the implementation of a eReuse commons, with the participation of several social organisations (see Section 7) and more than 700 computers already under reuse. The main contributions are the definition of the organisational and governance models, the definition of a circularity licence combined with end-user and circuit agreements, and the development of an algorithm to automate the estimation of the use value.

The next section presents the context, terms, and related work regarding the circular economy. In Section 3, we describe a commons-based cooperative platform, including the external and internal organisational and governance models. In Section 4, we propose a set of licences that limit the freedom of the current owners of the devices in the eReuse commons and restrict them from sending the devices that still have a value of use for someone else to reuse. We introduce the concept of community devices/products where a community is in charge of the custody of a circular economy. The use value of these devices is determined by a public algorithm, described in Section 5, that estimates use values based on characteristics, aesthetics, and functionality. The development of the governance model and licences are the result of pilots of this platform cooperativism model.

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The implications and lessons learned are discussed in Section 6, with concluding remarks and future work in Section 7.

2 THE CIRCULAR ECONOMY

The concept of a circular economy can become very elastic. Its meaning can vary drastically depending on the interests of the person who defines, uses, and implements it. For example, it is considered circular to burn waste for the generation of energy. If accepted, could the burning of a product that could have been reused be considered circular? We should check to what extent it has been attempted to first reduce, reuse, or only recycle at the end, as proposed by the rule of the three Rs, which we will introduce next.

Fellner et al. [6] studied scenarios of only recycling without reuse and estimated that our CO_2 footprint is reduced by 1.6%. Clearly, we will not reach the Intergovernmental Panel on Climate Change (IPCC) 50% reduction target by 2050. This is assuming that we manage to recycle 100% of the raw materials of products (that implies ignoring the second law of thermodynamics) and that all materials are recycled in recycling plants and are not exported illegally (today, we only achieve up to 20% [2]).

The aim of the rule of the three Rs is to maximise the practical benefits from products and minimise the generation of waste. The proper application of the three Rs can have several benefits. It can help prevent emissions of greenhouse gases, reduce pollutants, save energy, preserve resources, create jobs, and stimulate the development of green technology. This simple rule indicates an order of preference:

1. Reduce Reduction and minimisation are alternative names for this strategy; less waste is generated simply because waste is avoided. In principle, this includes repairing products (at home or in a repair shop), reducing packaging and packaging for more than one use, and policies against single-use plastic bags, among others.

2. Reuse To use something again with the same function that was originally conceived, but by different people who are not the original owner. This is where all second-hand and exchange websites and markets are categorised, with or without warranty. Often the product needs to be refurbished; it means checking, data cleaning, hardware inventory, component cleaning, or repair.

3. Recycling Dismantling, fragmentation, disassembling, or separation of the parts of a waste and the subsequent conversion to material for another process or product. If a product or component that is potentially reusable is in the waste stream, it can be prepared for reuse, a process similar to refurbishment but which can only be conducted by authorised waste agents. The preparation for reuse is the only process by which a residue can be turned back into a product. In the case of waste electrical or electronic equipment (WEEE), it is typically regulated by law (e.g. Decree 110/2015 in Spain).

While the reduce and reuse rules apply to products, the recycling rule applies to waste. These rules are not themselves circular; it depends on their order of application and the decisions made. This relates to the definition of circular economy systems 'keep the added value in products for as long as possible and eliminates waste'[3] or to the mission of zero-waste movements (no generation of waste).

Nowadays, a large part of the responsibility for keeping products alive rests with the user. The user decides whether to recycle the products he or she considers waste, regardless of their status (whether it works or not) or any demand for reuse if it still has enough use value for someone else. Once a product is considered waste, it can hardly be returned to a product unless it is prepared for reuse by authorised agents. This flow (from recycling to reuse) is not mandatory in most countries, with exceptions like Spain, which requires manufacturers to prepare at least 4% of the products sold in Spain for reuse [11].

In our view, the key is how to eradicate premature recycling so that only those devices with low use value or no demand for use enter the waste stream through recycling. At the public level, policies should empower the user to be able to self-repair devices, putting pressure on manufacturers not to limit the right to repair, including self-repair, or promoting eco-designed products that facilitate self-repair. Our challenge is to prevent products from prematurely entering the waste stream. In other words, how do we ensure that the holder of the object does not dispose of the product and, instead, channels it to a reuse circuit (a group of coordinated entities sharing a pool of devices).

Premature recycling can be avoided with a model in which the ownership of the product does not reside with the user, but in a higher sphere, that of a community or organisation that maintains the correct application of circularity. With this measure, we are forcing consumers not to dispose of products if they still have use value and thus demand for reuse.

In the following section, we present a theoretical framework and community of product custody, which promotes the prevention of waste because the transition from product to waste must be justified based on an algorithm (last section) that determines when the use value and demand of a device is low, so it can be recycled. In Section 4, we describe the set of formal agreements included in a licence developed and implemented by communities and organisations that prevent users from dumping products that still have use value for someone.

3 PLATFORM AS A COMMONS

The common property (or common-pool resource; CPR) governance model [13] is a traditional and recognised model for shared resource systems. Common property systems include social arrangements that regulate the preservation, maintenance, and consumption of natural or human-made resource systems, also called CPRs. The eReuse.org CPRs [8] focus on the circular life of digital devices and consist of a core resource, a pool of digital devices and data, that provides a limited quantity of extractable fringe units that can be harvested or consumed (computing services) by the participants.

Open commons [12] are expressly open for participation by any stakeholder that is willing to contribute to its sustainability in exchange for the benefits it can extract (computing and related services). In contrast to natural commons, such as fisheries or forests that are given and limited, open commons are extended by new participants as they contribute the required resources, digital devices in our case, to expand the capacity and coverage of the infrastructure. The eReuse commons represents a global federation of local groups, organisations, and communities that deal with the circular life of digital devices in their target communities under specific business models. They cooperate to share information, methods, services, and tools under a common governance, constituting an ecosystem around circular electronics. The participation in eReuse is not limited to accessing the resource system for consumption or contribution of digital devices, but it is also open for participation in the management and definition of its governance rules, agreements, procedures, and limits. Moreover, the commons, open or limited due to capacity, is a self-organised structure; therefore, sustainability depends on and benefits from contributions from all participants. However, resilience and sustainability are key to preserving the commons and remaining productive or operational.

According to Frischmann [10], such infrastructures generate positive externalities (or positive effects) that benefit society by creating opportunities and facilitating many other socio-economic activities. Therefore, pooling digital devices creates great social, economic, and environmental value, leaving a greater margin for added-value activities and generating more local impact than commercial infrastructures developed competitively. Commercial infrastructures are typically oriented towards extracting market value from second-hand devices and recycling the rest. Thus, CPRs make a great difference in developing regions or communities and in environmental preservation. The exchange of devices inside a circuit is oriented towards covering the cost, not based on the exchange of market value, where external exchanges can be done at market value.

Coordination across the eReuse commons is not only defined by democratic governance principles and protocols but also facilitated by a set of software tools, services, and applications [9]. That reduces the friction on the circulation of financial and social value among the participants and stipulates norms that create a more equitable and fair digitally mediated economy, in contrast with the extractive models of corporate platforms, according to the principles of platform cooperativism.

We can distinguish two scopes in the eReuse commons: local and global. Devices are typically shared locally, while anonymised data about devices are shared globally. Therefore, the platform involves local groups but can share data as part of a federation of these local groups through the common tools and procedures in eReuse.org.

3.1 The external organisational model

The CPR model holds and governs the resource system. The participants (individuals or organisations with their own rules) must accept the rules to join the resource system and must contribute the required resources, but they keep the ownership of their contributions and the right to withdraw. However, such CPR is supported by and provides benefits to its social, economic, and environmental context.

We look at these CPR from the perspective of a business model, as it clearly articulates *'The rationale of how an organisation creates, delivers and captures value'*. This allows the understanding of how circuits organise to generate and distribute social and economic value in a sustainable, adaptable, resilient, and participatory way.

We focus on the generation of social value (from device usage) and financial value (from the investment and expenditure to achieve financial sustainability along the circular chain and to generate a surplus that can be reinvested locally). For a commons perspective, 'business' can be understood as activity that results from the opportunity of device usage, obtained from a commons device pool by its participants. Alternatively, it can be called the sustainability model. This internal activity in a circuit is cost oriented or cooperative (in the sense of ensuring that costs are covered and that margins can be reinvested) and not profit-oriented or competitive (in the sense of extracting benefits from the community to be given to external investors).

The business or sustainability model, a business model 'canvas' (BMC), in Figure 1, is represented in one diagram that shows how everyone relates directly, indirectly, or even potentially (anyone that can be related) to a circuit, how that infrastructure generates social value from the consumption of the extractable resource (device usage), and how everyone contributes to developing and maintaining the core resource (the pool of devices).

The eReuse commons is structured in circuits; local groups of stakeholders cooperate under specific local governance rules to manage a pool of digital devices, as a social infrastructure for sustainable and accessible citizen computing through access to digital devices. Four main groups of stakeholders exist [8] among the *participants* (see Figure 1):

i) Volunteers are concerned with aspects such as environmental sustainability, governance of the resource system, software development, repair, protection of consumer rights, protection of citizen rights, and protection of the environment. Volunteers can contribute to identification and promotion of contributions (registering devices in the system) and management and allocation of digital devices to future users according to needs or social support.

ii) Professionals are interested in added-value services to distribute, refurbish, repair, retail, enhance, or recycle second-hand devices.

iii) Customers or end users are interested in using environmentally friendly reused devices or simply more cost-effective devices.

iv) Public administrations are interested in managing specific attributions and obligations to regulate the participation of society, monitoring environmental effects and data protection and satisfying their own needs regarding computing devices.

The *key partners* are the following external enabler agents that make the circuit work (see Figure 2): donors, distributors, refurbishers, retailers, collectors, recyclers, users, monitoring organisations (auditing manufacturing, such as Electronics Watch, repair, such as the Restart project, or reuse performed by eReuse.org, and environmental impact done by governments and non-governmental organisations (NGOs)).

Preserving a balance among these and other stakeholders is desirable. Ensuring the presence of key enabler agents is necessary, as every group has natural attributions that should not be delegated or undertaken by any other.

Devices enter the CPR primarily through three channels: 1) the collective purchase of new or used products, 2) charitable donations from public administrations and companies, such as those of a city council seeking to feed the local economy and reuse their surpluses for target groups in vulnerable situations, and 3) donations from other members belonging to the community, some of whom specialise in carrying out these fund-raising activities (buyback), members of cooperatives (e.g. Abacus.coop), or a recycler who has stocks that cannot be processed internally.

Devices are donated to local circuits according to a licence of their choice, with their preferred terms and conditions (e.g. traceability: return after usage or recycling, non-profit receivers). Receivers obtain devices and must accept the terms of the licence.

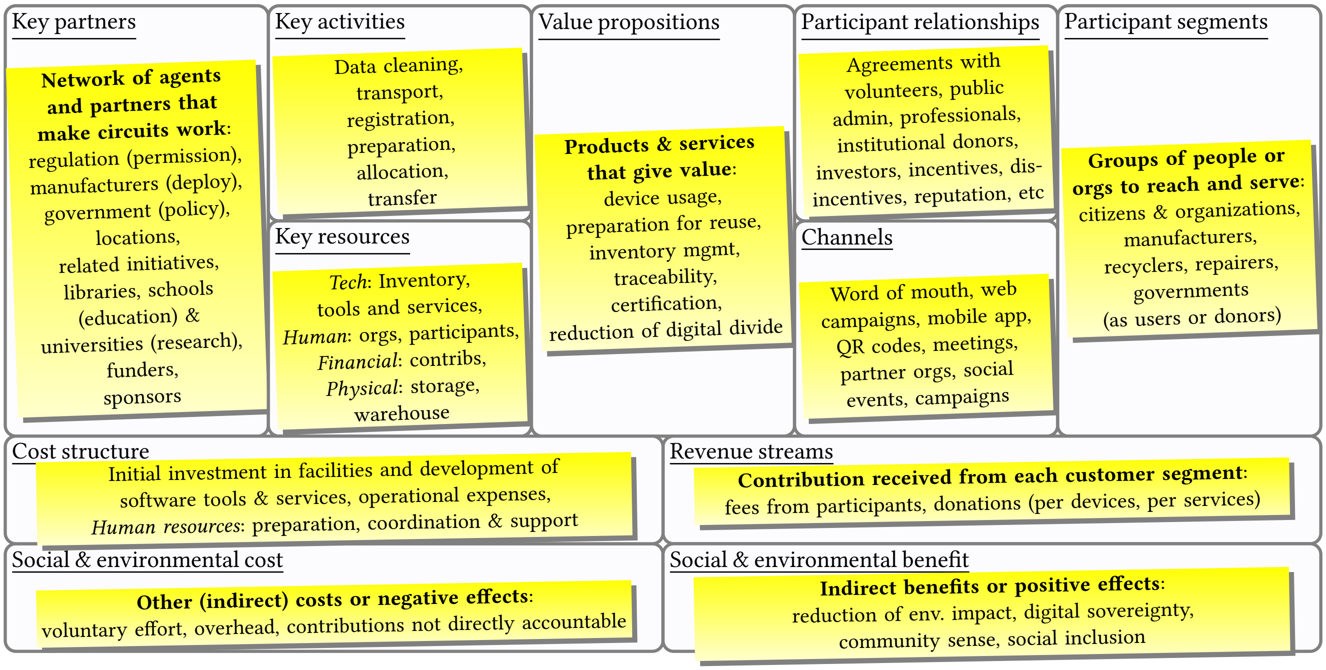

Figure 1: A template for the canvas of the outside view of an eReuse.org circuit, inspired by the Pangea circuit

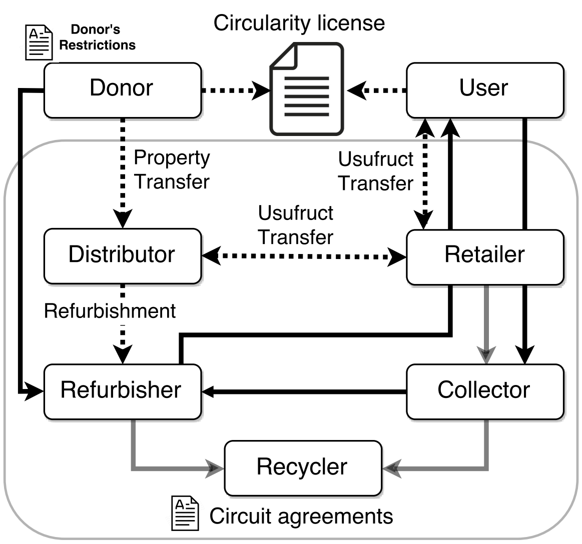

Figure 2: Agreements and flows during a device life cycle

Although the community is the custodian of the products, it is necessary to designate those directly responsible for the custody of the life cycle of the products. When a product enters the CPR, who will be responsible for its remanufacturing or refurbishment (remade by), who will deliver it to the end user (distributed by), what target group of recipients it may have (e.g. individuals or social entities) (reused by), who may receive it to the end user to ensure that it does not leave the community circuit (collected by), and who may recycle it (recycled by) must all be defined.

The commons to be preserved on the platforms are the devices that are captured, used, shared, improved, and finally, properly recycled. The use values of the devices are calculated when they enter the system (see the algorithm in Section 5) and for each transition, only leaving the system when the use value is too low or there is no demand for reuse. The sum of all devices gives the value of the running use of the platform. For example, the eReuse Catalonia Circuit today has a total of 700 devices in circulation with an average use value of 3.4 out of 5 units of use, this gives a use value of 2,380 units of use. Our estimate is 15,000 hours of use per unit of use, so the potential reuse in eReuse.org Catalonia is $15{,}000x2{,}380 = 35M$ hours of computer use.

End users consume these hours of computer use in exchange for a financial contribution, and this supports the revenue stream. Participants perform repairs, improvements, and maintenance services on the devices and are compensated economically. The platform has established a use-value relationship with an exchange value. Currently, one unit of use value, in the case of desktop computers, is equivalent to 20€ of exchange value. For example, if a participant makes an improvement on a device by increasing the use value from 2 to 4 units, this increase of 2 units of use corresponds to 40 € ($2x20$ €).

The environmental benefit results from the hours of computer use consumed monthly. This indicator represents an extended lifetime with a double environmental benefit, avoiding the manufacture of new devices and the generation of electronic waste. Another benefit is that the devices are properly recycled by the circuits. The social benefit is calculated based on the hours of computation consumed by socially excluded segments and voluntary contributions from participants in the learning and social-service context. Damaged and hard-to-repair devices are diverted to service-learning centres where students learn how to repair them. In these cases, there is a contribution of use value, and students are not compensated economically.

If the licence allows it and the centre takes responsibility for the equipment, it can be used by students in a situation of digital fracture.

3.2 The internal organisational model

In contrast to the outside view of the external organisational model, which shows how a circuit interacts with its environment, the internal organisational model represents the architecture of the governance instruments involving the participants of a circuit that makes its external organisational model work. From our experience with different CPRs [1], this can be summarised into five groups, represented by five layers as shown in Figure 3 from top to bottom: (i) good practices, (ii) procedures & internal regulations, (iii) agreements, (iv) ground rules, (v) local socio-legal framework. Each layer includes several related elements represented as boxes and enabled by the organisational instruments in layers below.

Circular device circuits exist in a given **local socio-legal environment**, defined by a large set of practices and rules that apply in that given legal regime around manufacturing, use, reuse, and recycling. Local choices will be required to build in that environment. The most relevant legal aspects in our case are the regulations and legislation regarding manufacturing, repair, refurbishment, donation, data protection, e-waste management, and environmental impact. The most relevant social aspects relate to local social values and typical local structures (typical governance models locally), contributions (either voluntary work, economic, material, professional, or corporate social responsibility), political values of the participants, and environmental impact. These legal and social aspects define the organisational environment and condition the choices. Whatever is done in a given locality is shaped by these applicable necessary conditions.

A circuit must define the **ground rules**. Either formal or informal, there are three elements that define the commitments, rights, and obligations and therefore the limits that shape participation in the community: the *end-user agreement*, the *circularity licence*, and the *collective governance principles* expressed by the commons circuit licence of the community that define the general principles and rules established by the circuit to regulate itself, governing its internal affairs. This can be more or less unstructured, depending on the needs and characteristics of the participants and environment.

However, there may be a set of additional internal **circuit agreements**, typically required for the participation, contribution, and exchange by certain types of participants, such as schools, universities, companies, and public administrations that regulate access and usage of devices or organisations that perform professional economic activities.

The set of ground rules and agreements define a framework where specific **procedures** and internal regulations can be established. Again, these can be more or less formal or rigid, as needed. We have identified six main categories: procedures for *communication and interaction*, procedures for *reporting* information sharing, procedures for *coordination* of decision making, procedures for *crowdsourcing* for accounting and compensation of contributions in terms of human, material, or economic resources, procedures for actions or *interventions*, such as collection, repair, preparation, and recycling, and procedures for *conflict resolution* to handle and resolve any conflict, including the outcomes (eventual sanctions).

On top of the procedures and regulations, we find the **practices** (the daily life of the community) that combine and implement the different procedures and regulations according to the conditions defined by the agreements, ground rules, and socio-legal environment. From these practices, we can identify *good practices* (legal, economics, social, environmental, and technical) that represent learning outcomes of an organisation and therefore should be highlighted and encouraged to be repeated given good experiences. Obviously, good practices define, by exclusion, 'bad practices' that should be avoided. These good practices can be very specific and dependent on specific details regarding the internal or external organisational models (local ways), or they can be generalised or adapted to other environments (generic or adaptable patterns).

In the case of new devices, *distributors* frequently have a business relationship with the manufacturers that they represent, while *retailers* consist of small and large for-profit businesses that sell products directly to consumers (*users*). The donor that represents the manufacturer for new devices donates devices free of charge to a distributor involved in a circuit. For example, the Barcelona City Council (donor) has a donation agreement with Pangea.org (distributor), a non-profit organisation. Pangea does not refurbish or sell (retail) but adds them to the common pool of devices of a circuit. Pangea provides the service of acquisition, distribution, and management of compliance of the chain of custody for the donor.

The donor-distributor donation agreement defines restrictions that the distributor must preserve throughout the complete life cycle of the device until its final recycling. Three examples of donor restrictions could be: 1) refurbishers and retailers must be non-profit organisations, 2) users should be also non-profit, and 3) the price paid by the user must be cost oriented and not profit oriented (e.g. the price in the second-hand market). Compliance with these restrictions is key to the preservation of the commons in a circuit. Therefore, circuits must ensure that their information system allows them to report on compliance with donor agreements.

The distributor shall retain ownership of the devices until their final recycling, but the usufruct will be transferred. The refurbishers in a circuit collect devices from donors and perform a basic inventory, without restoring them yet. The responsibility of collection rotates among refurbishers, and the selected refurbisher will pick all devices from a donor. The inventory is shared with retailers, and they can see the characteristics and use value of the pooled devices. Retailers choose the devices they can channel to users. The retailer-user service agreement charges all these costs to users. Retailers then compensate the distributor and refurbishers, or other agents involved with technical support and transport to the end user.

The main conflict in a common pool of devices is the quota of devices assigned to each retailer. The quota to be received by each retailer is related to its situation of compensation with the commons, which, in the case of retailers, is the difference between the extracted use value and the returned use value; for example, we assume that a retailer extracts 300 use-value units (100 devices with a use value of 3 each) but only returns 100 units (50 devices with a use value of 2 each). To compensate their situation, they should contribute 200 units of use value, either by providing devices to the commons in the role of a distributor or by making contributions of similar value (monetary or other equivalent).

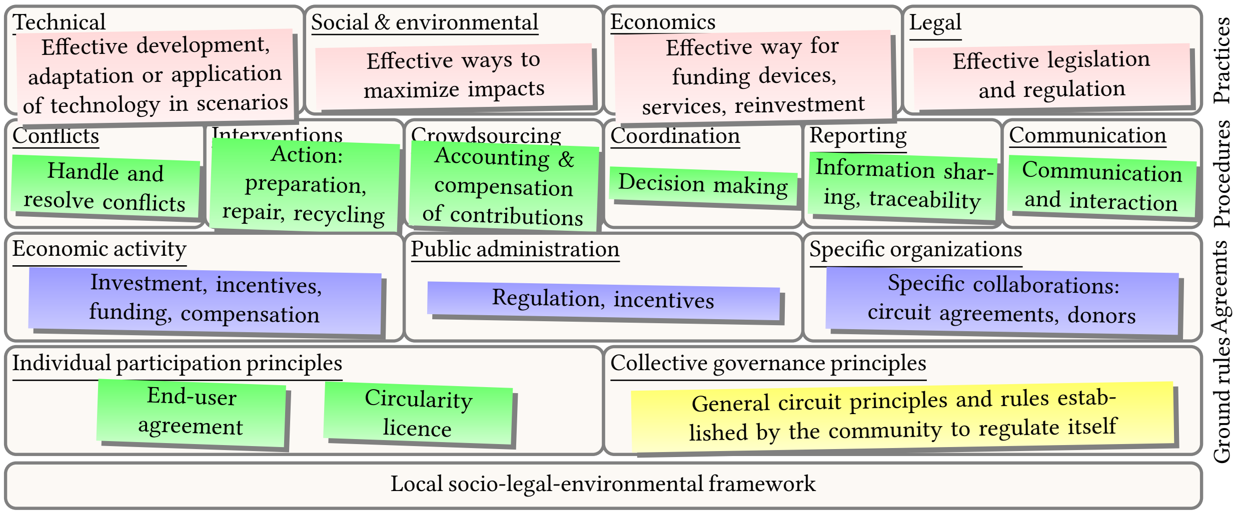

Figure 3: The general principles of an internal view for eReuse

Finally, the user will look for the device at the refurbisher, or the retailer will send it to the user. Circuits define the agreement with the end user, which may force the receiver to return the device when it is no longer in use.

4 CIRCULAR PRODUCT LICENCES

Prevention of waste generation can be avoided with a model in which the ownership of the product does not reside with the user, but in a higher sphere, that of a community or organisation that safeguards its reuse and circularity. With these measures, users cannot get rid of products if they still have a use value and a demand for reuse. This restriction on the freedom to dispose of products, turning them into waste, and our pilot experience in the last years, has resulted in a licence that is linked to the products obtained by end users.

This licence has three levels or parts (see Figure 4). The first part, circularity, is aimed at platforms or organisations that safeguard the reuse and traceability of products until the final recycling. The second part is specific to each group of interacting organisations that constitute a circuit. The last part is addressed to the end user, with a commitment to follow the return mechanism of a product once the user wants to stop using it.

4.1 Circularity licence

The circularity licence proposes a set of rules to inform circularity and preserve data sharing among organisations, what we call the eReuse.org global commons. In this article, we present the main licence terms or rules, and details can be found in the eReuse.org website. The licence terms applicable to organisations or communities in custody are:

1) Preserve the chain of custody: If a product ends up in a landfill, whose fault is it? For this reason, traceability of products must be reported during the reuse cycles up to recycling.

2) Publish the value of use in recycling: How do we know if a product has been recycled prematurely? The organisation in custody of a product must keep the internal traceability information (internal chain) of the products the organisation manages. Likewise, at the moment the product becomes waste, it must make the information public (external chain) regarding the product and the waste manager to whom it is transferred.

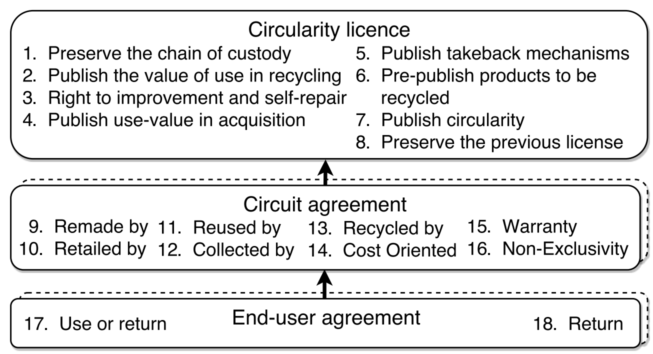

Figure 4: The three parts of the eReuse licence

3) The right to improvement and self-repair: Is self-repair allowed? The end user must be free to improve the product without losing the warranty or breaking any law, and the user must be given the right to self-repair after the warranty period has expired.

4) Publish the value of use in the acquisition: The end user at the time of purchasing a product is able to know its value of use and the multiplier applied. The multiplier is the result of dividing the exchange value or market value by the value of use. For example, a product with a use value of 3 and an exchange value of 60€ has a multiplier of 20.

5) Publish take-back mechanisms: The end user should know which is the existing mechanism for returning the product once it is to be disposed of.

6) Pre-publish products to be recycled: How do we know if products are recycled with an existing demand for reuse? Organisations in custody should publish the products in a marketplace before deciding to recycle them if there has been a demand for reuse.

7) Publish circularity performance: How do we know the circularity performance of the organisation? Circularity performance contains three indicators: the value preservation, the life extension indicator, and the loss of products managed.

8) Preserve the previous licence: Are the product terms and conditions preserved throughout the product life cycle? There may be products that can only be refurbished, distributed, and reused by non-profit organisations, etc.

4.2 Circuit agreements

The circuit agreement is the second part of the product licence and is specific to an organisation to ensure the refurbishment, distribution, collection, maintenance, and recycling of the products it manages within a community or in isolation.

The terms within this agreement include the following:

9) Remade by: Who can carry out the refurbishment processes?

10) Retailed by: Who can distribute it to the end user? In the case of new products, they are distributed directly from the manufacturer. In the case of used products, they obtain them from the refurbisher with a second-hand guarantee.

11) Reused by: Which segments of the product usufructuaries can be during reuse cycles? They are the end users of the product even if they do not have the property of the product, for example, segmentation by geographical area or by typology: individuals, social entities, etc.

12) Collected by: Who can collect the products from the beneficiaries? The role of this agent is to apply the valuation algorithm to decide whether the product can enter a new cycle of reuse or must be recycled. It can be conducted by the same user to optimise transport costs.

13) Recycled by: Who can carry out the preparation processes for reuse and recycling (dismantling, fragmentation, disassembly, or separation of the parts of a waste and subsequent conversion to materials for another process or product)? The community will reward an effort to always apply Level 3 of the waste hierarchy (preparation for reuse) before Level 4 (recycling).

14) Cost oriented: Should the price paid by users be cost oriented or market oriented? How do the agents of the platform divide the economy generated by the sale or renting of equipment? To make the model transparent to consumers, platforms can reference the algorithm used, following the standards set by eReuse [7], or make specific versions. In any case, it must be transparent to the user.

15) Warranty: What model of warranty applies to the products that the community distributes? How long is the warranty period, and what compensation model applies in case of product failure?

16) Non-exclusivity: This term defines the common pool of products. Can any organisation access products to restore, maintain, or distribute, or are products reserved for a particular entity? This term is often fixed by public administrations that do not want their donations to benefit particular entities.

4.3 End-user agreement

This is the last part of the licence and is primarily for final consumers. Some are just consumers who are authorised to use resources (withdrawal) under an end-user licence. Some are possessors who bring in or use their devices. They can be volunteers or providers of professional services or both under different terms of participation.

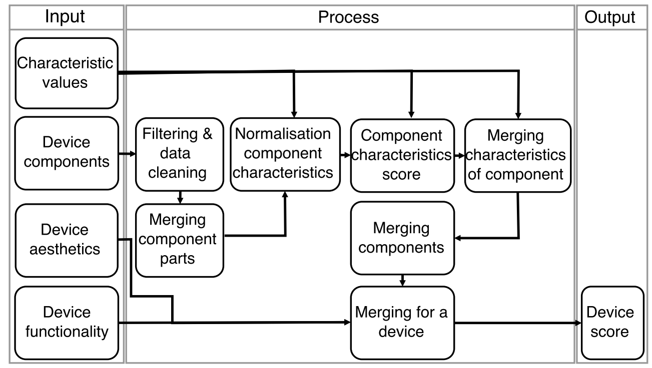

Figure 5: Algorithm to estimate the device score (use-value)

All participants are eligible to contribute to manage the digital infrastructure (define and decide on its rules, features, coverage, price, investment, and access rights) and its ownership (alienate or resell it).

The terms within this agreement include the following:

17) Use or return: If the user stops using the product, should he or she return it to the community to be reused by another user?

18) Collection points: Can the user dispose of the product in any collection point or must it be returned at specific points of the circuit?

If the licence allows it, a particular user could play all roles, as long as they comply with the terms of use. For example, if a user wants to get rid of a community product, he or she can take on the roles of collector, refurbisher, and retailer. The first step would be to update the use value by means of the algorithm (explained in Section 5). The second step is to share the device with the community and have it suggest a future user or give him or her the freedom to propose one that is included in the role of 'reused by', for example, a social entity, a school, or another individual.

Community products may have defined roles (remade by, retailed by, reused by, or collected by) at the reuse cycle level. A device can have a reused-by licence from non-profit entities in the first cycle of reuse but a reused-by licence by private individuals in the second cycle of reuse. It is very common to find situations in which professional restorers refuse to restore devices with a low use value, and these are referred to educational institutions (service learning; e.g. Fundació Marianao) where students in computer vocational training courses repair equipment that is then reused by students at home. This allows new reuse cycles to be created for those devices with a very low use value that would otherwise be recycled.

5 ALGORITHM TO ESTIMATE USE-VALUE

This algorithm is a logical step-by-step method to solve the problem of estimating the value of use of desktop and laptop computer equipment[1] as seen in Figure 5.

5.1 Inputs

The inputs correspond to the main characteristics of a device:

Device components: the components it has, such as the processor, storage, and RAM memory;

[1]More details are available at https://github.com/eReuse/Rdevicescore

Device aesthetics: the aesthetics or appearance, which is a categorised variable, defined subjectively with values, such as the device is A: new, B: in very good condition (small visual damage in hard-to-spot places), C: in good condition (small visual damage in easy-to-spot places, and not on the screen), etc.;

Device functionality: and functionality, another categorised and subjective variable, such as A: all works correctly (buttons) and no scratches on the screen, B: hard to press button or small scratches on an edge of the screen, etc. At the same time, each component has a set of features, such as processor speed, number of processor cores, processor score according to benchmarks, disk size, read/write speeds, RAM size, and CPU speed.

Characteristic values: The use value of a product varies over time, for example, in 2018, computers with less than a dual core processor and 2 GB of RAM are unsuitable for most operating systems and common applications. These variations in use value can be found in the table for 'Characteristic values' that contains updated acceptable performance values for each component. This table is developed as a consensus process among all eReuse participants.

The use-value function: The values for acceptable component performance are the input for the component use-value function. This function is monotonically increasing and continuous with three sections (see Figure Figure 6). In the first section, we need low growth. In the second, we need high growth, and in the third, we need low growth. The x-value (component characteristic performance) of the function is normalised between 0 and 1 as each component has a different range (e.g. RAM size ranges 0–16 GB or more and disk size ranges 0–1000 GB or more).

The reason for a score function with three sections is our interpretation of use value. A component must have a certain performance to be useful. Once the performance of a component is satisfactory, its weight is reduced in the overall score of the device. For instance, values of RAM size should be increasing slowly from 0 to 2 GB, as these values are less than acceptable (Section 1), from 2 to 4 GB values should increase rapidly, as a relevant change (Section 2), and from 4 to 8 GB, it should increase slowly, as it is less relevant (Section 3). Acceptable values for each component correspond to the start of Section 2. For the example of RAM size, $xMin = 0.08\,GB$ and $xMax = 8\,GB$. Applying the standardisation formula $y = (x - xMin)/(xMax - xMin)$, we have $0.242 = (2\,GB - 0.08\,GB)/(8\,GB - 0.08\,GB)$

5.2 Process

Filtering & data cleaning: Since platforms can manage diverse electronic devices, such as televisions, printers, and computers, the algorithm should filter the input to only accept desktop and laptop devices or should treat each category differently. The input with the description of the device components needs to be cleaned as an input to the algorithm. For example, in a device without a disk, the input is a null value to be converted to 0.

Merging of component parts: There are components that are divided into parts, such as RAM memory with multiple memory cards or storage with multiple hard disks. After merging, they are treated as a single component. For example, two 100 GB disks result in 200 GB, but a 2 GB–100 MHz RAM card combined with a 4 GB–200 MHz results in a 6 GB–166 MHz.

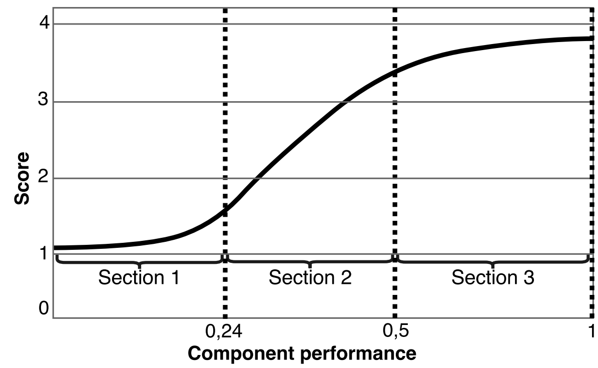

Figure 6: Function to estimate component score (use-value)

Normalisation of component characteristics: In this step, we normalise the characteristics of the components between 0 and 1. We use the table 'Characteristic values' with $xMin$ and $xMax$ and standardise the values: $y = (x - xMin)/(xMax - xMin)$.

Component characteristic score: In this step, we give a score according to our function to estimate the component score as shown in Figure 6. This function gives low scores to products that do not satisfy a minimum of usability features, as mentioned above.

Merging the characteristics of a component: In this step, we merge the various characteristics of a component. Here, we carry out the harmonic mean weighted by the weight of each characteristic (harmonic mean (weight)):

$$Score_{comp} = \frac{ram.size.weight + ram.speed.weight}{\frac{ram.size.weight}{ram.size.score} + \frac{ram.speed.weight}{ram.speed.score}}$$

Merging components: In this step, we merge the various components into a single component. Again, we calculate the weighted harmonic mean. Established community weights are 50% for processors, 20% for disks, and 30% for memory. The result is a unique score.

$$Score_{dev-comps} = \frac{proc.weight + drive.weight + ram.weight}{\frac{proc.weight}{proc.score} + \frac{drive.weight}{drive.score} + \frac{ram.weight}{ram.score}}$$

Merging for devices: From a score, grouping all the components, we now merge a simple sum for the other scores for aesthetics and functionality. If aesthetics has an A rating (like new without visible damage), this represents 0.3 score points, and if the functionality has an A rating (all works perfectly) that will be 0.4 points.

$$Score_{final}[0{,}4.7] = Score_{aest}[-1{,}0.3] + Score_{funct}[-1{,}0.4]$$

5.3 Output

The result is a value ranging from -2 to 4.7, but the negative values are assigned a value of 0, as we do not consider that devices have a negative use value. This value is interpreted as the use value of a device. A value within [0, 2) is considered unusable; this device either does not have all the necessary components or has insufficient performance to run an operating system and the most common applications. A device within [2, 3) is considered low range, which is sufficient to be used, but with limitations. A device within [3, 4) is considered a mid-range device that can be used for most applications, and a device within [4, 4.7] is a high-range device.

6 DISCUSSION

Acceptance of the circular licence. This part of the licence obliges the user to report the traceability and use value of the devices during the life cycle. The participating entities of eReuse Catalonia Circuit and other entities with internal circuits accept this licence by federation with eReuse. At first, there was confusion about the data to report to eReuse. It was feared data were reported about users using the devices, when only custody and public information, such as the collection point or the final recycler is reported. Fulfilling this licence is considered a differentiating factor by the donors of the equipment in being able to ensure their chain of custody, but the effect on donors has not yet been observed in reporting the use value at the time of recycling.

Acceptance of the circuit agreement. In the Barcelona community, currently, 10 entities participate, performing the roles of capturing, restoring, distributing, and recycling devices, while other entities provide help-desk services to end users, circuit management, and software as a service for the management of the community circuit. The entities have defined working rules, and this has served to develop the circular licence.

Acceptance of the end-user agreement. This part of the licence obliges the user not to discard the devices if they still have use value or demand. Today, there are hundreds of users who have accepted this licence. Users are returning the devices for three reasons: 1) the price of the device is at cost and not at market, 2) the distributor offers mechanisms that facilitate the return, and 3) in some cases, the distributor requires a deposit to be returned when the product is returned. Some users adopt the product use licence just from personal motivation.

We have seen that, when the use value of waste is much higher than the value of the raw materials they contain, there is a risk of informal reuse circuits. If the use value is similar to that of raw materials, the profit margin tends to zero, and we reduce the incentive for an informal circuit to appear.

7 CONCLUSIONS

We have presented a commons platform for a circular economy model of digital devices and the accompanying data, which is focused on traceability. This platform has been developed with the eReuse.org community during the last three years. We described the business model of eReuse, the external business model, and internal governance model. The product licences, developed in collaboration with pilot participants, are the key component for the governance of the community, while the remaining procedures are being developed and formalised. The automation of tasks, such as the estimation of use value, is key to increasing the efficiency and reducing the cost of processing. Product licensing encourages reuse and traceability for recycling. A circular licence obliges owners to audit the use value of their products throughout the entire life cycle. With this licence, the end user is no longer the owner and can no longer decide whether goods should be recycled or not; instead, this decision is transferred to the community or organisation responsible for the stewardship of product circularity. This community is supported by a contract that executes an algorithm that certifies the value of use and potential demand.

Ongoing and future work is around the use of the blockchain to publicly report traceable and irreversible public data about transactions and traceability information. We are investigating the use of smart contracts to digitally facilitate, verify, or enforce the negotiation or performance of agreed organisational procedures. There is also ongoing work on the extension and optimisation of the algorithm to estimate the use value including more types of devices and components. For an automatic evaluation of aesthetic aspects, a 2D automated scanner is being built that, combined with machine learning, is expected to speed up and generate more objective evaluations of devices. Additional metrics and data are being considered with respect to related processes, such as the provenance of raw materials in digital devices, labour, and environmental rights in manufacturing, repairs, and formal and informal recycling processes.

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Computer Reuse at UPC started in 1995, with the UPC Reutilitza programme, under the auspices of the school of Informatics (FIB) and the Centre for Cooperation for Development (CCD). The inspiration for this work results from service-learning activities in the campus association 'Tecnologia x tothom (TxT)' (Technology for everyone). Many friends contributed. Thanks go to Fermín Sánchez for leading the efforts, to David López for starting the doctoral path, and to Xavier Bustamante, the one responsible for the technology that supports the community and my initial partner in this. Santiago Lamora, Garito, Adrià Sánchez, Ivan Vilata created the first implementation of the eReuse tools. Raquel Núñez, Óscar Fabián, Mayra Pastor, and Rosario Pastor participated in several pilot projects and communication campaigns. Stephan Fortelny, Jordi Nadeu, and Mireia Roura, today, actively contribute in software development and in defining the licence and business model for eReuse. Many organisations and people have participated in the eReuse circuit and have contributed to improving the model: Miquel Caballé from Solidança, Marisa Gliosca from Andròmines, Antonio Naranjo from Abacus Cooperativa, Jordi Sebastián from Alencop, Raimon and Ibon from Reciclanet, Marc Serrano from TriniJove, Ugo and Blanca from The Restart Project, Keith from ComputerAid, Björn from Electronics Watch, Charles Brennick from TechReuse, and Javier and Martí from Jamgo.

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