Property rights in servitisation: a practical assessment with reused computers

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Abstract. The circular economy of computers is about producing fewer, more durable and reusable products while investing in expanding their life span through a functional service economy. Reuse is often mentioned as a sustainable solution to linear consumption's negative impacts. Shared ownership has potential advantages in life span extension computers over individual ownership. Moreover, it allows understanding how computers are used during their reuse phase to estimate lifecycle impacts and evaluate circular business models. This paper aims to identify specific success factors and barriers for shared property in four empirical cases of reused and servitised computers launched by eReuse, a collaborative computer reuse platform in Barcelona. The scope of the study is the impact of reused computers under different ownership-sharing scenarios and roles involved. Ethnographic action research and quantitative data help us analyse to what extent shared ownership models manage to lengthen the life span of computers and what roles and life extension strategies are beneficial to its optimal functionality. We found that roles as maintainers or activities such as product and software upgrading are essential to ensuring the dynamism and flexibility required to keep computers functional for an extended lifespan under a shared ownership model.

Keywords: circular economy, digital devices, sustainability, platform cooperativism, environmental impact, social impact, climate change, software tools, public policy

1 Introduction

Since the Club of Rome report [26], it is evident 50 years later that humanity has failed to design, produce and sustainably maintain digital devices. As the main ingredient of economic growth, the accelerated consumption of digital products trespasses the environmental and social limits of the planet. Solving the problem requires taking into account many dimensions.

The circular economy, and reuse, in particular, propose a sustainable relationship between people and ICT devices and related services. From its environmental dimension, all electronic devices can be a resource, with minimal or no e-waste, and designed considering the durability, reuse, repair, upgrade, and repurpose. From its social and economic dimension, reuse also delivers ICT devices at affordable prices whilst promoting decent work in decentralised economic activities and local services and markets.

This paper describes the eReuse scheme, based on pooling ICT reused devices and services as a critical resource system. That requires innovative circular business models based on common property rights, sharing ownership, and servitisation, where ones own the devices, others refurbish and maintain, and others use but do not own. All this considers environmental, social and economic gains and encourages community investment and contributions.

Following the perspective of common-property resources and incentives for long-term investment in the improvement of resource systems [35], we have characterised property-rights regimes that distinguish among diverse rights from different roles in four empirical cases in eReuse.

The use of refurbished computers in two servitised cases and two ICT facilities based on use cession has been followed for 4.5 years. The eReuse tracing software has allowed us to measure intensity (life span and usage hours during the first and second ownership period) and do a preliminary lifecycle analysis using the triple business model canvas. The characterisation of the eReuse property regimes has been integrated into the first layer of the triple business model canvas to discuss its influence on related impacts in the environmental and social layers. The contribution of this paper is to identify success factors and barriers, key roles and activities that ensure longer-lasting computers under a common property regime.

Our method combines ethnographic action research [39], more specifically, networked action research [10], with iterative, technology-driven experimentation. We also performed semi-structured interviews and meetings with different roles: refurbishers, distributors, maintainers, and public administration. We have discussed our results and model with Allemaal-digitaal (All Digital), Digital Inclusion in Luxembourg, Computer Aid, and Electronics Watch to validate the applicability [34].

This paper is organised as follows. Section 2 introduces the circular economy of computers in the context of sustainability and lifecycle impacts during the reuse phase, specifically its relationship to shared ownership business models. Section 3 describes background project research of the eReuse model, while section 4 analyses its conceptual schema of property rights regimes. In section 5, we analyse the four empirical cases using a Triple canvas framework to synthesise life cycle impacts and their intersections. We discuss related work in section 6 to help us in the discussion in section 7. Finally, we conclude with main remarks and future work in section 8.

2 The circular economy of computers

Reconciling the right to use ICT with the right to live in a healthy and just world as a safe space for both humanity and the planet [32] is a global challenge. That is reflected in several SDGs (4, 10, 12, 13, 15 and 16), by the 2016 Paris Agreement and by related ITU recommendations to reduce by 2030 to half the environmental ICT sector footprint of what it was in 2015 [22].

Despite that, we are doing the opposite: estimates for 2040 ICT-related emissions account for 14 % of global emissions [22] due to a consumption increase. Currently, more than 6 billion new ICT goods are sold annually worldwide [37], after a long and unclear process full of environmental and social blind spots during its extraction and manufacturing. Other problems with a linear economy are premature obsolescence and underutilised lifetimes, [31], the opacity of the reverse chain, the recycling efficiency [9], and the 51.3 % of world households without a computer during the COVID-19 pandemic. [21]

The circular economy relies on the principles of "designing out waste and pollution, keeping products and materials in use, and regenerating natural systems" [11]. Circularity enables business models based on eco-efficiency and the green economy (needed for the global south) to social models based on sufficiency and functionality (needed for the global north). But some circular models are more "circular" – or better – than others. It all depends on how much an attempt has been made to reduce and reuse, and only then recycle, as proposed by the three Rs rule of reducing, reusing and recycling.

Also, some circular models are more "social" than others. The circular economy is "an economic model that seeks to respond to human needs and equitably distribute resources without harming the functioning of the biosphere, or crossing any planetary boundaries" [17].

Regarding computers, the circular economy is about producing fewer, more durable and reusable products while investing in expanding their life span. But in reality, there is a context of obsolescence and underutilised computers, with first-use ownership periods reported lasting between three to five years [30]. IT asset management companies tend to replace entire fleets of laptops at three-year intervals for reasons like maintenance efficiency rather than functional obsolescence [2]

User behaviour influences the life span of products. A product's actual lifetime rarely reaches the upper threshold of its designed lifetime due to emotional and socio-economic factors jointly [5]. With computers, rapid accounting amortisation is part of the wide range of attributes that also influence digital devices' lifespan and obsolescence reviewed by [3].

In the current context, collecting still functional computers to extend their life span may be a solution. The benefits of reuse, and business models associated with the second-hand market, have been widely reported in the literature. The second of the 3Rs rule allows achieving the best use of computers by maximising their lifetime, helping to decarbonise the environment, reducing social inequality with affordable markets, and creating jobs in repairing or refurbishing [27].

However, we should take into consideration that any circular material loop needs new materials and energy injected [7], or reuse cycle. For example, reusing computers can be associated with new materials related to product upgrading (RAM, solid disks) and using the computers during their second life. Nor will sustainability be achieved if improved efficiency is offset by increased consumption [6]. A complementary approach would be the slow down the way computers are used up (slow consumption).

In addition to energy consumption, reuse faces the challenge of remanufacturing functional computers that replace first-hand ones. Moreover, many socio-economic factors affect second use. Therefore an understanding of these multiple factors is essential to prevent rebound effects, as reported by [40] and [25].

2.1 Business and individual ownership models

In a linear economy, manufacturers and distributors promote collecting computers for, in many cases, premature recycling. That results from an interest in removing still operational computers from the market. That benefits demand at the expense of producing more e-waste.

Acquisition, short use and premature recycling of computers follow a private property rights scheme: the purchase is followed by a relatively short period of use until a decision to replace the device, given the need for the supply chain to continue selling new units. The relationship between short-term use and the economy has long been recognised as a strategic goal to stimulate consumption and economic growth at the expense of rising environmental and social impact. However, this short use period leaves little room for circular economy strategies to increase computers' life span through repair, maintenance or refurbishment.

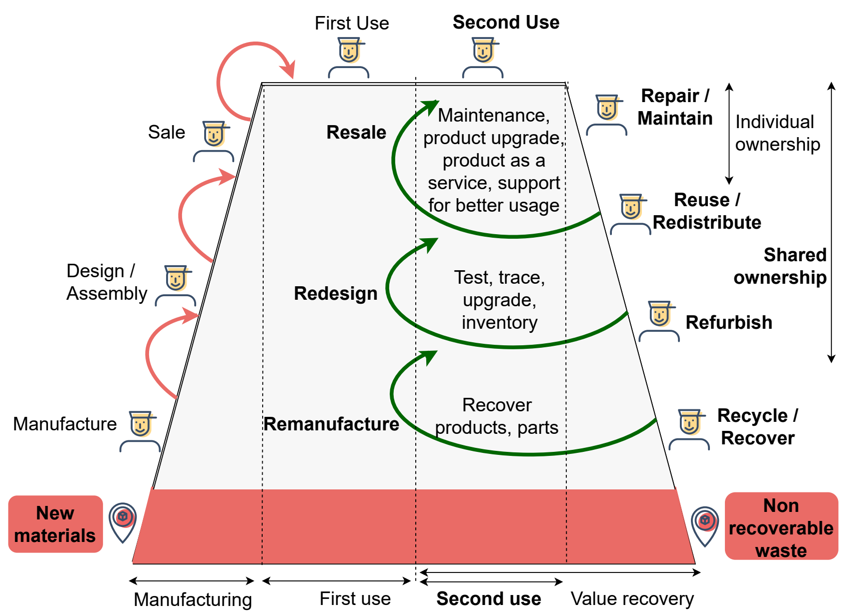

Fig. 1. The value hill of the circular economy of digital devices: value versus lifespan.

In Figure 1, we introduce the value hill [1]. It represents the change of value over time, as a tool to visually compare business models based on a linear economy and individual property with models based on communal property. In linear models, as the computer owner, the user has the power to decide on their repair, maintenance, and reuse in its nearby networks, but not on refurbishment or reuse centres, since the latter decision is not in its hands. In contrast, other models can strengthen preventive maintenance and boost repair by retaining the use-value in circular loops through inter cooperation among several actors, including refurbishment and reconditioning processes.

Ownership retention allows "the transformation of the actual linear production-focused industrial economy into a utilisation-focused service economy operating in loops" [36].

Retaining use-value through cycles is often associated with product-service systems. These business models provide cohesive delivery of products and services, ranging from shared systems to rental or systems based on common-pool resources (CPR), where the property rights remain in the fleet manager. In all these systems, ownership is displaced in exchange for service provision. Their emphasis is on addressing customer needs rather than selling physical ownership [6].

That "User-service" model has advantages, such as flexibility in utilisation, little need for product knowledge, green status, etc. In contrast, the fleet manager ensures a constant value over a long-term utilisation period through products and services.

Fulfilling users' needs requires maintaining function over time and roles in facilitating product upgrading and repair. All prevent product dysfunction and reduce the overall system cost. In other words, it encourages design to maximise profit over the second product life span.

3 Electronics reuse: eReuse

Outlined in [15], eReuse is an initiative and an action research project in which a diverse and dense set of actors in different roles cooperate in what are called circuits. They capture decommissioned computers from private and public institutions to create common-pool second-hand computers ceded for use to entities and citizens at prices oriented to circularity costs.

The project started in 2015 with a donation, and by 2022 more than 10,000 computers were processed with their own open-source software tools[16]. In addition, they have developed software tools that allow circuits to certify and optimise the refurbishment process, report ownership changes, trace to ensure final recycling, and monitor collected data to obtain impacts and durability metrics, [14]

In Barcelona, 15 entities associated with the eReuse circuit work locally under principles described in previous works ([12] and [13]) and developing experimentation projects with communities [28].

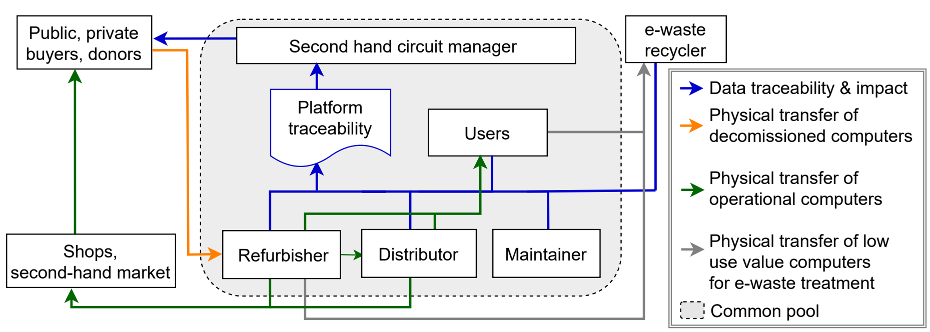

Fig. 2. eReuse model: actors, transfers in a common pool resource system.

In Figure 2, we can see that only one of the actors, the second-hand circuit manager, mediates with donors as an umbrella for the other actors that participate in the local circuits. These actors are refurbishers, distributors, maintainers, and communities with computer needs. A donor contribution is formalised by a single agreement that benefits all actors and avoids the need to go to public concurrence in the case of public donors. This scheme can allow even large volumes of computer donations. In return for the donation, donors will receive detailed impact reports.

The second-hand circuit manager formalises the agreement with a donor, but computers are directly delivered to refurbishers. These refurbishers can receive financial compensation for data wipe as a service to the donor (up to EUR 20). Computers are put in a rack to be registered and traced with eReuse software at the component level, wiped, inspected and tested. Those not passing the test are sorted out for recycling and recorded in the system as prepared for recycling. Those that pass the test are cleaned, checked in more detail, sometimes upgraded (in terms of battery, RAM and storage), reinstalled with (usually) a Linux operating system, and registered in an inventory.

Inventories of prepared computers are shared with second-hand distributors or directly with final users. These are citizens who prefer second-hand for environmental or affordability reasons; public social services demanding local ICT products and social organisations. They receive computers for use in cession mode, at prices between EUR 40 to 120, or in pay per use in a servitised model.

In servitised cases, the role of maintainer complements the ecosystem that ensures a functional device through software updates and hardware repair or replacement and support in case of any incident. There are also training and assistance agents on the ground to ensure that vulnerable beneficiaries have the necessary computer usage skills in some cases.

Part of the sustainability of this circular model is directly related to feeding, preserving and maintaining this pool of shared devices, the resource system. At the same time, entities in a circuit receive a cost-oriented economic compensation. In the case of the second TIC manager, these compensations are linked to management costs of working with donors, which involves dealing with receipts, keeping track of the chain of custody, compliance, fulfilment of commitments, and reporting impact. Other compensations for the other actors are transport, storage, refurbishment/repair, distribution, and cession of use management,[1] and maintenance.

In practice, the economic viability has several limitations related to a net positive or value considering the overall cost (processing the device) and benefit (usable device). Examples are the adequate capacity of second-hand devices to replace a new device (substitutability) with the sometimes blurred boundary between what is a product and what is just waste according to supply and demand [33].

eReuse follows a common-pool resource model [29]. That is a traditional and recognised model for shared resource systems that include social arrangements that regulate the preservation, maintenance, and consumption of natural or human-made resource systems, as an in natural or artificial commons [4].

[1] Equivalent to the concept of usufruct, or comodatum in Roman law.

4 Collective ownership model and the bundle of rights

Institutional and social arrangements are needed to transfer property rights between donors (public and private institutions), the circuit roles, and between these roles and final users. An initial introduction of a circuit organisational and governance model, as well as circuit agreements and licences, has been defined in [13, 8, 34].

Property rights can be seen as a bundle of rights [35], understood as agreed-upon and enforced prescriptions or rules requiring, forbidding, or permitting specific actions for actors under different roles. In eReuse circuits, that bundle of rights entitles over a pool of computers coming from a donor. That bundle of rights allows the transfer of the right to computer use to authorised end-users: specifying who will get them and when and how they will be recycled.

In our scheme, the most powerful *alienation right* is the authority to transfer a computer to a recycling centre or a computer retailer if the donor allows (see Figure 2). This right gets transferred from the donor to a second-hand circuit manager. When the potential for reuse is too low, the circuit manager decides to alienate the device to a recycling entity, and refurbishers receive economic compensation for it. No other role in the circuit, not even the end-user who receives the computer for use in cession or servitised, has that alienation right.

Although donors usually lose the right of alienation as a result of the donation, they maintain the *exclusion right*, understood as the authority to define the qualifications that circuit roles and final users must have to access the donated devices. In short, the donor's motivation or political mandate can translate into rules that implement the exclusion right. For instance, what type of reuse centres can refurbish/recycle computers (exclusively non-profit entities, for example), the degree of traceability to be reported, and the range of target end-users who can use these devices.

The *management right* defines the operational level that governs the allocation and use of a pool of devices. The authority to determine how, where and when actions will be taken to define the operational level is transferred from the second-hand circuit manager to all the roles that participate in a circuit: refurbishers, distributors and maintainers. That also includes the management of financial compensation across the value chain in circuits.

Users have *withdrawal rights* to extract computing services from the devices they receive.

Property rights over devices get transferred through agreements (de jure) or informal arrangements that improve efficiency without increasing bureaucracy (de facto). Similar principles apply to all participants that contribute and benefit from being entitled to participate, as *access right* to the device commons.

Based on these rights, there are four types of roles associated with eReuse property rights:

- The *owner*: the second-hand circuit manager decides for a device in the pool to be reused or become waste.
- The *proprietor*: The public or private device donor institution regulates who will have access to the devices and who can participate in the circuit.

- The *claimant*: associated with the management of the extended life of devices. That is the case of refurbishers, distributors or maintainers that work to extend the device's useful life as much as possible by upgrading, refurbishing, repairing and reusing it, and ensuring adequate functionality.
- The *authorised user*: final users have the right to use the device and reconfigure it as long as they inform the circuit.

Therefore, claimants have the management right to decide which authorised user receives and uses each device. That is the case of an association that receives computers to distribute them among individual members under their criteria. If a donor transfers the exclusion right to a circuit, owners have the right to sell the devices in the open market (shop).

5 Results

eReuse has more than 10 thousand traced computers, of which 2 thousand are ceded for use or servitised in ICT local facilities. To analyse the differences between cession of use and servitisation and to study the influence of rights of bundles in lifecycle impacts, we have analysed four experimental cases with a total sample of 37 computers.

"Torre Baró" and "La Bordeta" classrooms. We analyse an ICT public classroom with nine computers laptops from the common pool in a servitised model co-created in 2018 between several eReuse actors and the economic development agency of the Barcelona City Council (Barcelona Activa). From the end of 2018 to the present, several eReuse actors provide a provisioning and maintenance service of software and reused hardware in the Torre Baró centre. There, Barcelona Activa technicians run teach activities to promote employment in citizens of the Nou Barris vulnerable neighbourhood. The activities do not require devices with high computational capacity beyond a processor, RAM and hard disk that allows text editing and web browsing. Their use, not too intensive, is 2 hours for one or two days a week. This model was replicated with variations in 2019, in La Bordeta, in the Sants neighbourhood, with six computer laptops of their own.

"Ton i Guida" classroom. In this third empirical case, we analyse the cession in April 2017 to the ICT classroom "Ton i Guida" of 9 computer desktops from the common pool to provide hardware but not maintain hardware or software. That is a cultural centre self-managed by a platform of entities that offers meeting points, information services and a cession of spaces to support the associative network of the Roquetes neighbourhood.

"Banc dels aliments". Finally, we analyse the case of "Banc dels Aliments", an entity created in 1987 to provide food to second-tier entities that have historically been working with reconditioned computers, serving 70 volunteers and 12 employees. Since 2019, much of its equipment has been obtained, free of charge, from a reuse centre attached to eReuse, which, in return, uses its facilities and logistics. In this case, we analyse a sample of 13 towers.

To align the business model of the four cases with property rights and roles and the impacts of the life cycle, we have used the triple-layered business model canvas

(TLBMC) [24]. The objective is to visualise a summary of the activities that the roles of the circuit can carry out according to the bundle of rights, the resources necessary to develop the activities, their cost structure and their impacts.

The triple canvas has been evolving due to learning from three cycles of experimentation-action. In the cases of Torre Baró and La Bordeta, an attempt has been made to guarantee the servicing and maintenance of hardware and software while alleviating the risks when buying second-hand, having flexible contracts and a structure adaptable given the successive lockdowns caused by COVID-19.

5.1 Business model, roles and rights

We have associated the concept "partners" with our actors under roles in an eReuse circuit on the economic business model layer in Figure 3. To represent their relationship with the bundle of rights, and associate the activities they can perform according to collective property regimes, we have coloured the economic layer according to the four identified roles (proprietor, owner, claimant, and authorised user) and their prevalence over alienation, exclusion, management and withdrawal rights. Boxes that are not coloured are not associated with any particular role or right.

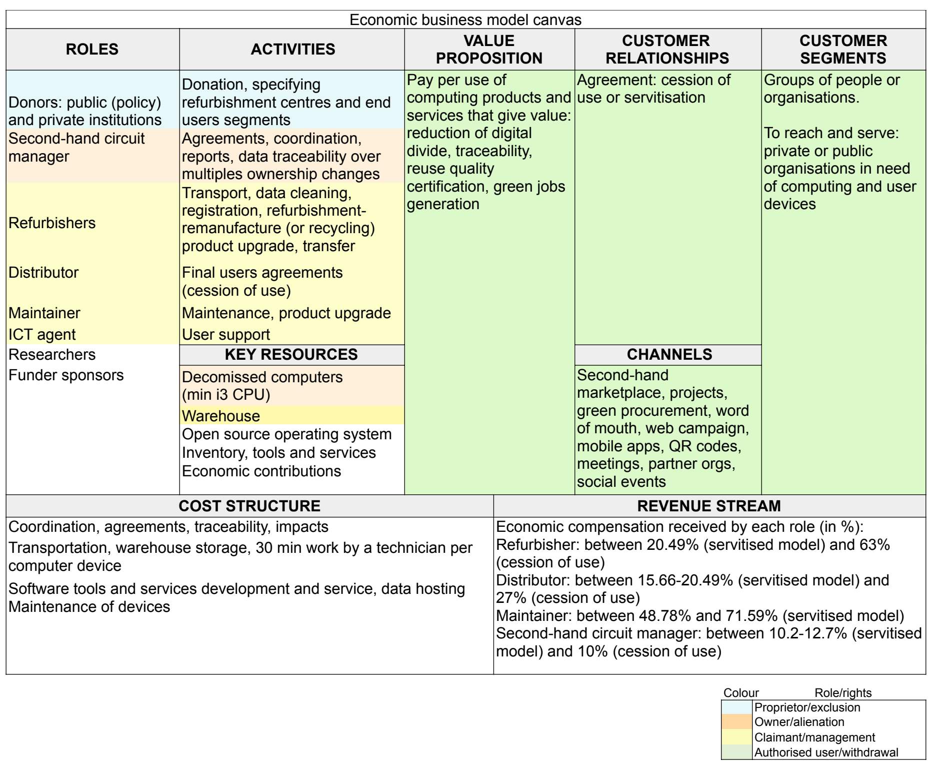

Fig. 3. Economic business model canvas

5.2 Economic impact

The creation of services associated with long-lasting computers has been a source of economic activity. Income in the four experimental cases has been analysed for an approximate economic impact.

In the case of Torre Baró, which used computers from the pool, the costs for Barcelona Activa during the first year were EUR 66 per computer for the first month (due to refurbishment and set-up costs) and EUR 16 for the rest of the months (excluding VAT). In the case of La Bordeta, in which the devices were for internal reuse, the cost per device during the first month (with the initial setup cost) was EUR 31.2, while for the rest it was EUR 13.5. For both cases, the cost structure, which we can see in Figure 3, varied throughout the annual periods.

In Ton i Guida, the cost of a device in a cession of use was EUR 50, divided into a structure very different from that of the previous models. In addition, the centre decided to install Windows 10 and Microsoft Office, so the cost of the licenses made the total price much more expensive.

At Banc dels aliments, there is no cost associated with the device nor a compensation structure associated with the roles since it is a barter and volunteer-driven economic model, which assumes the cost of maintenance.

The economic model appears to work according to the perception of the diverse stakeholders that find it satisfactory and attractive.

5.3 Environmental impact

To evaluate environmental impact, recommendation L.1024, [23] on Life Cycle Assessment (LCA) has been taken into account due that its focus being the potential impact of selling services instead of equipment. We have limited our study to Global Warming Potential (GWP) over a specific time frame of 100 years.

To estimate the data of extraction, manufacturing, distribution, treatment in the end-life and distances of transport, the Ecoinvent dataset has been used.

To calculate the impact during the two phases of use, we have considered the hours of use, since these were captured just after their first cycle of use (in the reuse centres), and at a certain moment during the reuse phase. The estimated power in active mode (0.2 KW for a desktop and 0.06 KW for a laptop), has been multiplied by the percentage in which the device has been active (73.33 % Ecoinvent estimate) and by the total hours of use. To this value has been added the resulting operation of multiplying the power in standby mode (0.005 KW for a desktop and 0.004 KW for a laptop) by the percentage in which the device has been in standby (26.67 % estimate) and by the total hours of use. The resulting value has been multiplied by 0.4363, according to the carbon intensity of electricity in Spain in recent years[38].

Finally, to evaluate the environmental benefits, the carbon footprint of a reused device (scenario A) has been calculated, compared to the alternative, the acquisition of a new device (scenario B). For scenario A, we have considered the extraction, manufacturing, transportation, collection, and distribution for second-hand use, and the contribution of the total hours of use. For scenario B, the extraction and manufacturing of two devices have been required, as well as two transportation, one treatment in the end-life and the contribution of the total hours of use. We have been able to compare the KgCO2/h for scenarios A and B and the rate of improvement as the result of subtracting both divided by the KgCO2/h of scenario B. In terms of abiotic resource depletion, computer reuse results in use hours that do not rely on the new materials required to manufacture another computer.

The periods of ownership, both in first and second use, have been calculated based on the computer BIOS installation date as an indication of the manufacturing date. The period between this date and the date when a refurbisher centre registered the computer in the eReuse software indicates the duration of the first ownership period.

For the second period of ownership, we have considered the date on which the computers were invoiced to the four experiences and the date on which the hours of reuse were captured. We have analysed the 37 computers of the four experimental cases together. Figure 4 shows environmental life cycle impacts.

<table>
<tr><td colspan="5">Environmental life cycle business model canvas</td></tr>
<tr><th>SUPPLIES AND OUT-SOURCING
(KgCO2eq)</th><th>PRODUCTION
(KgCO2eq)</th><th>FUNCTIONAL VALUE
(time)</th><th>END OF LIFE
(KgCO2eq)</th><th>USE PHASE
(KgCO2eq)</th></tr>
<tr><td rowspan="3">Transport from Shangai to Barcelona port (2.48 for laptop, 8.88 for desktop)</td><td>Extraction and manufacturing (175 for laptop, 226 for computer desktop)</td><td rowspan="3">Extension of ownership years by a maximum of 13.28 years (up to 4.57 in reuse phase) and a maximum lifespan of 51,966 hours, up to 13,983 hours in reuse phase</td><td>Decision of replacement for computers with computational power ≤ Core2Duo with a mechanical disk, 3-4GB RAM (-15)</td><td rowspan="3">Average energy first use: 554
Average energy second use: 99</td></tr>
<tr><th>MATERIALS (KgCO2eq)</th><th>DISTRIBUTION
(KgCO2eq)</th></tr>
<tr><td>A new solid state disk: 4.48
New RAM: 8.72</td><td>End user takes care of transport of own device (0.10-0.37)</td></tr>
<tr><th colspan="2">ENVIRONMENTAL IMPACTS
(Contribution in % to the life cycle)</th><th colspan="3">ENVIRONMENTAL BENEFITS
(Improvement in % of KgCO2eq)</th></tr>
<tr><td colspan="2">Average from initial manufacturing and transport: 42.73%
Average first usage electricity: 47.07%
Average second usage electricity: 10.13%
Average second transport and distribution: 0.04%</td><td colspan="3">Between 5.75 and 45.14% efficiency with respect to the linear model</td></tr>
</table>

Fig. 4. Environmental life cycle business model canvas

5.4 Social impact

We have estimated the social impact from quantitative data (reported reused hours) analysis and semi-structured interviews focusing on maintenance, product upgrading strategies, decision replacement, and computers' functionality.

Figure 5 shows the impact on the number of beneficiaries who used the ICT classrooms of Torre Baró and La Bordeta and who got a job as a result. Specifically, the first had 1,068 hours of reuse of functional computers; and the second had 159, more affected by the COVID-19 outbreak.

The maintenance service aims at guaranteeing productivity with operational devices. That was achieved through continued support during working hours, resolving program incidents on-demand, and updating to a Linux Mint operating system. The laptops were cleared at least quarterly, and in some cases, components were replaced

Social stakeholder business model canvas				
LOCAL COMMUNITIES	**GOVERNANCE**	**SOCIAL VALUE**	**SOCIAL CULTURE**	**END-USER**
Donors Refurbishment centres in socio-economic inclusion programmes (social enterprises), maintainers and distributors associated with the social and solidarity economy and recyclers Public facilities, ICT classrooms for neighborhood communities	A network of roles working locally in reuse circuits as a commons **EMPLOYEES** People in labour inclusion programs, repair technicians, maintainer, supporters. Second hand managers, distributors	Offer social inclusion from refurbishment (sustainable income, jobs) Help citizens participate in digital society without contributing to increased environmental impact Feedback/measures of environmental impact savings	Culture of reuse/circularity, use of service and free technologies Public money, public code Public money, public hardware **SCALE OF OUTREACH** Social bonds between donors, final users, refurbishment centres, education around circularity	Benefits from efficiencies of computing access Access to knowledge and learning Access to public and private services Community participation and engagement: inclusion in community activities with digital elements Time saving

SOCIAL IMPACTS	**SOCIAL BENEFITS**
59,712 hours generated in 37 reused computers Torre Baró: 32 and 28 people used the service in 2020 and 2021, with 28 and 45% of job placements La Bordeta: 23 and 6 people used the service in 2020 and 2021, with 37 and 43% of job placements	Lower-cost computing for social inclusion Transparency from social impact (jobs created, computing hours delivered to users) Digital sovereignty, sense of community

Fig. 5. Social stakeholder business model canvas

to improve their functionality (solid-state disks). Still, currently, the replacement of these computers is being evaluated.

Both ICT facilities have socio-labour insertion techniques (ICT agents) to teach employment courses and facilitate, if necessary, the user's adaptation to a Linux operating system. Despite initial doubts, it has not been any limiting factor. People with a lack of ICT skills can be referred to municipal training courses.

At Toni i Guida, since April 2017, 18,134 hours of use have been recorded, but this does not imply a good device to satisfy user needs. The experience relies on cession for use without the associated maintenance. The centre has insufficient resources to maintain hardware and software, so it works based on sporadic help from users or volunteers.

The tower computers were delivered with Ubuntu, and for months they kept it despite pushback from classroom users and attempts to promote free software. Finally, a second operating system, Windows 10, was installed in coexistence with Ubuntu. As a consequence of the low computational power, computers started up very slowly and were often unable to perform several tasks simultaneously.

The functionality of the reused computers is average in Banc dels Aliments, which accumulates 40,351 hours in second use. The ICT volunteer team supports a virtualised fleet with several computers with different computational capacities and operating systems coexisting simultaneously (Linux/Win7 for towers with less than i3 CPU and Windows 10 OS). They started using Linux, but they abandoned it because virtualisation software is not flexible with open source-based operating systems. Furthermore, the virtualisation software must be reconfigured every time the computer is turned on, which means long waiting times for the user. Consequently, they are renewing their fleet with computers with at least 3 or 4 cores and 4 GB of RAM to be able to install Windows 10.

For Banc dels Aliments, second-hand computers mean that 30 % of the time of its volunteer ICT department is devoted to hardware and software maintenance of a high turnover fleet. Weekly activities are replacing hardware parts and providing solutions to software adaptability to hardware problems. Of course, going for reusability requires extra effort. But the fact that volunteers donate their time helps mitigate any cost overrun.

6 Discussion

Based on the coherence of the three layers of the triple canvas, which is necessary for sustainability, we can discuss the following aspects.

6.1 Alienation and exclusion rights

In our shared ownership model, the transfer of the alienation and exclusion rights from donors to second-hand ICT agents in a reuse circuit expands the life of computers up to 4.5 years, far beyond literature assumptions between 2-3 years in [2], or between 1-2 years in [20]. Moreover, this increase in use has occurred between the boundaries of the intrinsic durability of the computer, which results from design and manufacturing decisions. Finally, it shows that product longevity on second-hand is also conditioned to socio-cultural norms, as [6] points.

A change in the socio-economic variables can reverse a throwaway society model: lifetime expansion strategies have avoided the major initial environmental impact of producing a new device with raw material extraction and manufacture. Instead, the initial impact of a reused device has spread over a more extended period of use. After comparing the performance of computers in our circular model with the linear economy scenarios, which report a higher efficiency of between 5.75 to 45.14 %. In any case, they are positive results in line with other studies, such as those to [2], who estimates that environmental impacts of using second-hand laptops could be 39 to 50 % lower than for a new laptop purchase, and [20], who points out that such impacts could be between 10 to 50 % depending on age, functionality and ability to replace a first-hand asset.

6.2 Management rights

In our model, the environmental benefit is not synonymous with social benefit. The transfers of alienation and exclusion rights from a donor to a second-hand circuit manager alone do not guarantee computers' social impact. The functionality of reused computers, and their ability to replace first-hand ones, is the assumption on which the literature that estimates the environmental impacts of reuse is based.

In all four cases, adequate functionality depends on the presence, or absence, of the maintainer, a key role in management rights (computer use) and whose product upgrading decisions are vital to providing the ability to maintain the use-value of the CPR.

This consideration is crucial when working with reused computers and vulnerable populations to prevent rebound effects. "Just having a computer does not make sense", is the headline from [19]. A computer needs preconditions, such as support, to be useful. That is also shown in the Amsterdam city council program's report to face the digital divide during COVID-19: individual and group support was a key to ensuring device functionality and social impact. [18]

The importance of management rights and the maintainer or similar roles, like user support, translates into a functional service economy and a cost structure. In Torre Baró and La Bordeta, between 48.78 to 71.59 % of the circuit revenues went to this role. In Banc dels Aliments, the volunteer IT team spent 30 % of their time dealing with hardware and software. In contrast, in Ton i Guida's case, the absence of a maintainer means a relative negative social impact due to computers' dysfunction. In [33], we identified other cases of dysfunction due to a mismatch between real usage needs and initial plans, the expectation for Windows or specific applications (MS Office) while receiving computers with Linux operating systems, and computers overloaded when reinstalled with Windows (Windows 10 in our recent cases) due to lack of substantive competence in using Linux.

6.3 Product upgrading and decision replacement

As in [35], maintainers and refurbishers, as claimant roles, can invest in improving the resource system through product upgrading, both hardware (installing more RAM or changing disks, for example), software and operating system (installing Linux distributions) to ensure sufficient functionality of the devices.

Repair and product upgrading strategies that adapt the software to hardware requirements, and not the other way around, are part of the circular economy. Furthermore, these upgrades make it possible to continue using devices that are still functional but the donor discarded for several reasons, including proprietary software (e.g. Windows 11).

However, despite having large communities behind them, Linux-based operating systems may not be as usable for the users as other first-hand commercial offerings. In addition, refurbishers cannot give the same warranty as manufacturers. However, the presence of the maintainer can resolve dependency situations between end-users and refurbishing centres, improving the interaction with second-hand computers.

Regarding decision replacement, Core2Duo with 3-4GB RAM mechanical disk in all cases proved insufficient. eReuse circuits are receiving computer donations from Intel i3 processors, similar to other cases studied as Computer Aid and Digital Inclusion in Luxembourg [34].

6.4 Ecosystems

Circuits in eReuse follow a multidisciplinary and cross-cutting approach, and its scheme requires the adaptation and participation of several actors under a bundle of rights. Related to [32], we can see that on the triple canvas, four dimensions associated with actors are in eReuse circuits: i) public sector and public procurement practice and policies related to product life span (Barcelona City Council in presented cases); ii) shared and sustainable business model provided by the market (in our cases, refurbishers, maintainers and second-hand distributors associated to Social and Solidarity Economy); iii) the society, as the final users of ICT public or private facilities, and iV) the commons, the pool of devices managed under the described bundle of rights.

6.5 Limitations

Enabling ICT computing facilities under servitised or cession models is an activity that needs to be scalable to be economically sustainable. The outbreak of COVID-19 wholly affected the four empirical cases. Specifically, Torre Baró and La Bordeta interrupted their services from March to October 2020 and from this last month to January 2022. The pandemic also affected the replicability of the servitised schemes, given that Barcelona Activa has another 14 employment service points for citizens in the city.

Moreover, servitised public ICT computing facilities are difficult to sustain financially if not scaled up to other public interest initiatives (Barcelona Activa in our case). Also, financial issues need to be resolved. Refurbishers will not recover the value of the devices until 2-3 years later, depending on their durability, which is hard to foresee. So this is the role that assumes the most significant risk.

6.6 Future work

More empirical evidence is needed to expand the study sample to the 2 thousand computers in shared ownership that the eReuse circuit has in Barcelona. Likewise, improving the methodology for estimating impacts and studying rebound effects is necessary.

However, the combination of shared ownership, reused devices, free software and virtualisation has aroused the interest of free software advocacy organisations and other actors related to public policies. To achieve that, it is necessary to continue strengthening the social muscle of eReuse circuits.

7 Conclusion

The circular economy, and reuse, in particular, effectively help prevent extractivism and reduce the manufacture of new computers. Models based on common property systems, such as eReuse, allow a transition from individual ownership to shared (community) ownership, where diversity and density of actors collaborate to preserve a common pool of second-hand computers offered in a servitised business model at affordable prices. It allows to create a local economy and social impact and reduce e-waste.

Through empirical cases in different communities, supported by social enterprises and public institutions, we have used technology as a communication tool, as a data source needed for impact reports, and to trace ownership changes between actors.

We have found that property rights schemes are essential to connect impacts across economic, environmental and social layers in the studied cases. A bundle of rights allow actors in the ecosystem to take essential decisions such as recycling or refurbishing, investments and maintenance, and adapting decisions according to each socio-economic and cultural context.

Linked to the alienation right, we can conclude that collective ownership in common-pool resources retains the power to decide on the final destination of computer devices according to whether reuse or recycling is economically viable. Moreover, that can develop the ability to maintain and support final users' needs and make correct software and hardware upgrading decisions.

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