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Beyond Ownership: The Environmental Impact of Rent and Refurbishment of ICT devices

Method Report

IMPRINT

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Abbreviations

B2B	Business-to-Business
B2C	Business-to-Consumer
CBM	Circular Business Model
CE	Circular Economy
CFP	Carbon footprint of products (sometimes PCF)
CO_2eq	CO_2-equivalent
DE	Germany / Deutschland
EC	European Commission
EOL	End of life
EU	European Union
FU	Functional unit
GHG	Greenhouse gases
GWP	Global warming potential
ICT	Information and Communication Technology
ISO	International Organization for Standardization
LCA	Life cycle assessment
M	Mean
MD	Median
N	Number
SD	Standard Deviation
PCF	Product Carbon Footprint
POS	Point of Sale
WBCDS	World Business Council for Sustainable Development

Executive Summary

This report "Beyond Ownership – Environmental Impact of Rent and Refurbishment of ICT Devices" provides the methodological foundation for the industry report (Circularity 2025). It explains in detail how so called "circular business models" – such as device-as-a-service (rental) and refurbishment for second use – can be assessed and compares them to conventional linear use through scenario analysis.

The project focuses on four device types: smartphones, laptops, cameras, and gaming consoles, with smartphones being the primary example throughout the report. The main objective of the study is to evaluate the potential environmental benefits of circular business models, particularly those involving rental and second-hand practices, by investigating changes to the active service lifetime during the use phase.

The study builds upon a consumer survey conducted within the project (Circularity 2024) alongside other surveys and literature to analyse the flow of devices within Germany. The consumer behaviour insights gained were used to model device flows based on observed usage patterns. Potential parameters for circular business models are drawn from existing literature, data provided by associated project partners, and additional market insights from the authors of the study. Thereby, the scenarios do not represent specific activities by certain companies or service providers, but potential layouts how such services could look like on average in Germany.

Section 3 of the report analyses the current use phases of devices and the reasons and methods by which they are disposed of. A significant portion of electronic devices remains functional after their first use, yet many of these are not reused, resulting in missed opportunities to extend their lifecycle. Most devices are replaced not due to hardware failure, but for other reasons, presenting an opportunity for second-hand use. In fact, 35% of devices are passed on for potential reuse (e.g., gifting, trade-ins, or resale). However, only 14% of devices in circulation are second-hand, indicating a mismatch between supply and demand. This mismatch is not only reflected in the numbers, but also in the types of devices available. Devices that are traded-in or donated often fail to meet the quality expectations of second-hand buyers in terms of age, brand, or condition. Moreover, many non-broken devices are stored in households without further use (hibernation), presenting another untapped source for second-hand devices.

Professional refurbishment offers the potential to better align the available supply of used devices with existing demand by restoring products to a condition suitable for reuse, thus increasing the availability of second-hand devices. However, this potential is currently limited by the relatively low volume of devices entering refurbishment processes. Rental services, on the other hand, provide two key methods for extending the active service life of devices. Firstly, by renting devices out to multiple users in succession, and secondly, by ensuring devices are sent for refurbishment once they are no longer suitable for rental.

The second part of the report focuses on circular impact measurement (Section 4). Interviews with companies offering various components of circular business models revealed that these activities are deeply interconnected (see also Circularity 2025). Consequently, circular impact measurement should consider the entire device lifecycle rather than focusing solely on one activity or phase of use. Fictive scenarios have been developed to facilitate such comparisons.

The analysis confirms, in alignment with other studies, that extending product lifetimes through strategies such as repair, refurbishment, and resale is generally beneficial for the environment. However, the additional service life gained through these procedures is still considerably shorter than if reuse were incorporated into the average device lifespan. Circularity 2024 indicated that devices made available for reuse were typically used for a shorter duration during their first life. Furthermore, information on rental models from various sources suggested that rental periods tend to be shorter than the typical ownership duration of devices.

The scenarios and available data demonstrate that lifetime extension is environmentally advantageous, and the efforts required to facilitate such extensions are worthwhile. The report also highlights the need for further data collection from researchers and emphasises the necessity for service providers to gather detailed information from their partners in order to accurately estimate the environmental impact and potential benefits of their services.

1 Goal and Scope

The goal of this report is to provide a comprehensive scientific foundation for the environmental impact model developed as part of the UNDRESS Circularity project[1]. In contrast to the associated report (Circularity 2025), which focuses on broader insights and practical implications for stakeholders, this report goes into greater depth with regard to the underlying data, assumptions, and methodological decisions behind the model. It is intended to complement the market report, while also standing on its own as a detailed and self-contained analysis.

While the core methodological framework remains consistent across both reports, the scenarios, assumptions, and specific results presented here may differ in certain aspects from those shown in the Circularity 2025 report. These differences are intentional and serve to demonstrate the broader applicability and flexibility of the CBMI tool, including additional functionalities – such as the export module – and extended scenario variants that could not be included in the main report due to scope and space constraints. The case studies and calculations shown here are therefore not intended to replicate or validate the main report's results, but rather to illustrate how the methodology can be adapted to different contexts. Any differences in assumptions or scenario design are made transparent in the relevant sections and do not imply that one set of results is more correct than the other. Instead, they provide complementary perspectives that highlight the versatility of the CBMI approach. Readers are encouraged to view both reports together for a full picture: the main report provides the consolidated strategic view, while this report offers a deeper, more technical foundation for analysis and discussion.

The UNDRESS Circularity project is a collaborative industry initiative led by Circularity in partnership with Fraunhofer IZM, Systemiq, and twelve industry partners. These include Assurant, circulee, Everphone, FixFirst, Foxway, Grover, Ingram Micro Lifecycle, rebuy, Recommerce Group, Reverse Logistics Group, Deutsche Telekom, and Vodafone. The project was supported by the Deutsche Bundesstiftung Umwelt (DBU) and Deloitte.

The project addresses a central challenge in circular economy measurement: how to robustly assess the positive environmental impact of circular business models – specifically rental and second-hand – by focusing on changes in the use phase. This lifecycle stage, though often underrepresented in impact assessments, plays a critical role in determining the overall sustainability of consumer electronics. By analyzing changes in product usage patterns, intensities, and durations, the report identifies key levers for optimizing environmental outcomes.

Quantifying the current state of second-hand and repair practices provides a necessary basis for baseline modeling and scenario assessment. Extending product lifetimes through R-strategies like repair, refurbishment, reuse or resale can be beneficial from an environmental standpoint, if rebound effects remain within acceptable limits. However, the actual pathways that electronic products take after their initial use – whether they are reused, repaired, stored, exported, or recycled – remain poorly understood. Fragmented and inconsistent data make it difficult to assess how many products are given a second life and how many are prematurely discarded or lost in informal channels.

To address this, an approximation of the current flow of electronic products in the German economy is made, focusing on factors such as the functionality of devices after the first use, general repair and reuse rates, end-of-life outcomes, and the extent to which second-hand devices reduce the demand for new products. Particular attention is given to the decisions consumers make after the initial use phase, since these determine whether further use cycles are possible. This aspect is crucial for realistically modeling environmental effects and for developing strategies that can increase the effective lifetime of products.

Focusing on rental and second-hand models, the analysis centers on two device categories that differ significantly in their use behavior: frequently used devices (such as smartphones and laptops) and infrequently used devices (such as gaming consoles and digital cameras). This distinction enables a nuanced exploration of the diverse environmental potentials across product types.

[1] Project website: https://www.circularity.me/undress/

The data foundation for the model integrates insights from expert interviews, anonymized proprietary data provided by project partners, national survey results on the adoption of circular business models in both private and business sectors (Circularity 2024, 2025).Together, these sources provide a foundation for modeling realistic usage scenarios and evaluating emission impacts along the product lifecycle.

Although the current focus is on consumer electronics in Germany, the methodological approach is designed to be adaptable to other countries and industry sectors. By laying out the assumptions and logic behind the environmental calculations in a transparent and replicable way, this report serves as both a practical guide and a scientific reference. It is intended to support practitioners, businesses, and policymakers in better understanding and applying impact assessments for circular business models – while focusing more on the underlying scientific methodology and analysis, this study complements the practitioner-focused industry report by Circularity e.V..

2 State of Research

2.1 Environmental benefits of Circular Business Modell (CBM)

A Circular Business Model (CBM) is an approach to business that integrates the principles of the circular economy into its operations. Unlike traditional linear business models that follow a 'take, make, dispose' approach, CBMs are designed to minimise waste, maximise resource efficiency and keep products, materials and components in use for as long as possible. This is achieved by designing products and systems that are inherently regenerative, either returning to the production cycle after use or decomposing harmlessly in the environment (Geissdoerfer et al. 2020).

The research on the environmental benefits of circular business models (CBMs) is extensive and often the environmental benefits of circular business models are substantial but not always straightforward to achieve or measure. In a systemic review of 103 studies, Koide, Murakami, and Nansai (2022) concluded that although circular business strategies such as repair, refurbishment, reuse and rental showed moderate to high environmental benefits compared to linear consumption models, they were also associated with a rebound risk, resulting in lower environmental benefits than often assumed.

This rebound risk refers to the unintended consequence where the expected environmental benefits of circular models are offset by behavioural or market responses, such as accelerated replacement or increased overall consumption, resulting in lower environmental benefits than often assumed.

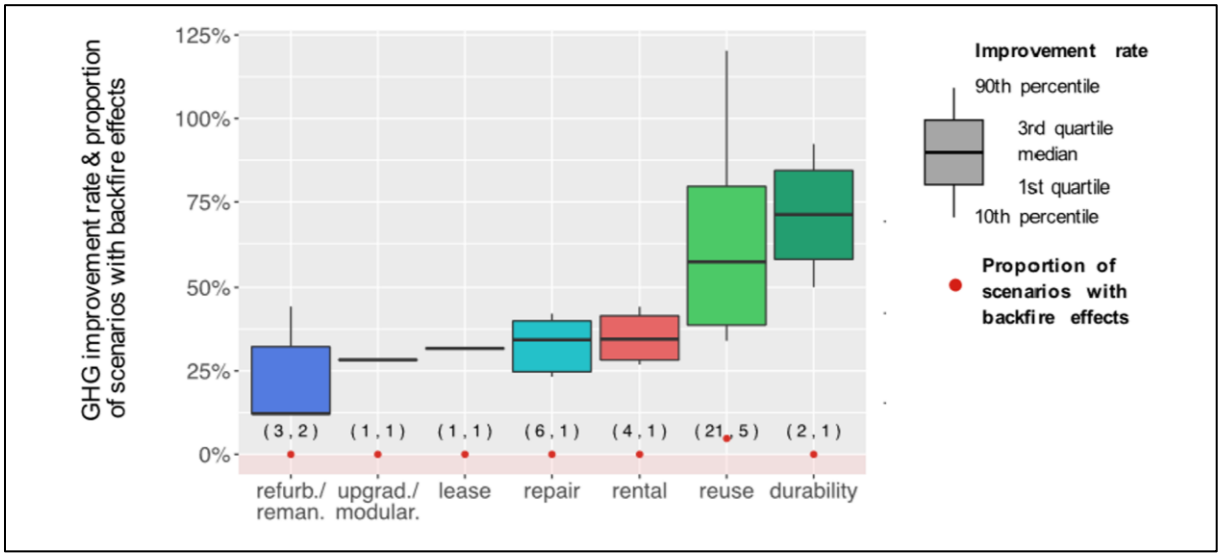

Figure 1: Impacts on global warming potentials by adopting circular economy strategies (chart adopted from Koide, Murakami, and Nansai 2022: Fig. 6.)

In their analysis of studies and related scenarios on ICT products, Koide, Murakami, and Nansai (2022) were able to show that the potential environmental benefits typically ranged from 12-57% (see Table 1). The potential environmental benefit is measured as the potential GWP improvement compared to buying and using a new product instead. These figures should be treated with caution as they are based on a very small sample of studies and scenarios, which were also calculated using different methodologies and assumption.

Table 1: Improvement rates by CE strategies for ICT equipment (Koide, Murakami, and Nansai 2022: Table S5)

CE strategy	Improvement rate of GWP (median)	Number of scenarios	Number of studies
Renting	0.35	4	1
Leasing	0.32	1	1
Reuse	0.57	21	5
Repair	0.34	6	1

CE strategy	Improvement rate of GWP (median)	Number of scenarios	Number of studies
Refurbishment /Remanufacturing	0.12	3	2

In another study, (Poppe et al. 2024) paint a similar and varied picture of the potential savings from CE strategies, with a particular focus on repair and refurbishment. They show from existing studies that the potential savings for ICT and other products are typically in a wide range of 24-91% compared to buying a new product (see Table 2).

Table 2: Potential environmental savings through repair and refurbishment (Poppe et al. 2024, Table 2-5)

Study / Source	Focus	Product group	Modelling approach	GWP-Saving through Reuse / Repair against New product
ADEME et al. 2022	**Refurbishment & Repair** Identification of potential savings through refurbishment for different environmental impact categories	Smartphones	Cut-off	87%
		Tablets		78%
		Laptop		77%
		Desktop Computer		73%
André, Ljunggren Söderman, and Nordelöf 2019	**Refurbishment** Study on the remarketing of used laptops with primary data from refurbishers	Laptop	Shared-burden	41%
Pamminger, Glaser, and Wimmer 2021	**Repair** Comparative analysis of various circular end-of-life concepts for smartphones	Smartphones	Shared-burden (economic allocation)	71%
Cordella, Alfieri, and Sanfelix 2021	**Remanufacturing**	Smartphones	Cut-off	52%
Maga et al. 2018	**Refurbishment** Study on the remarketing of used smartphones and tablets with primary data from refurbishers	Smartphones	Cut-off	46%
		Tablets	Cut-off	46%
Restart Project 2021	**Repair** Reference data for calculating CO2 savings through repairs. A simple saving of 50% is assumed from the repair compared	Various Electronic Devices	Cut-off	50%

Study / Source	Focus	Product group	Modelling approach	GWP-Saving through Reuse / Repair against New product
	to the production of a new appliance			
RUSZ 2023	**Repair** Determination of avoided CO2 emissions through repairs at the RUSZ	Audio devices, coffee machines, white goods, brown goods, small appliances	Cut-off	Ca. 91%

In their study, the authors explain the various reasons for this wide range, which not only depend on the quality of the empirical data, but also on the methodological choices made in the underlying studies, which will be discussed in detail in the next chapter. Despite the wide range of potential savings, the studies provide two important implications for CE strategies, which can be generalized as follows:

- In contrast to traditional linear consumption practices[2], studies indicate that circular strategies such as repair, refurbishment, reuse and renting ICT products have positive environmental benefits.
- Empirical studies have made it clear that CE strategies can only partially avoid the emissions otherwise associated with a new product.

2.2 Addressing avoided emissions in LCA

The transition from traditional linear consumption practices to circular economy (CE) strategies introduces new challenges and opportunities in measuring environmental impacts. One of the most significant challenges is accurately accounting for "avoided emissions" in Life Cycle Assessment (LCA). Avoided emissions refer to the potential reductions in greenhouse gas (GHG) emissions that occur due to the implementation of circular strategies, such as reuse, remanufacturing, recycling, and extending product life and other business solution, as opposed to following traditional linear processes.

Avoided emissions are emissions that are prevented or reduced through actions that replace more emission-intensive processes with less harmful alternatives. In the context of circular economy strategies, these avoided emissions can arise from activities such as:

- **Reuse and Refurbishment**: Extending the life of a product by repairing or refurbishing it avoids the emissions associated with manufacturing a new product.
- **Recycling**: Recovering materials from end-of-life products reduces the need for virgin material extraction and processing, leading to lower emissions.
- **Product-as-a-Service Models**: Offering products as services (e.g., leasing or renting) can optimize the use of resources and minimize waste, leading to emission reductions.

While the concept of avoided emissions is straightforward, accurately calculating and reporting these emissions in LCA poses several challenges:

- **Specificity versus Representativity**: Striking a balance between scenario specificity and broad representativity is challenging. Highly specific data may lack general applicability, while generalized data may overlook key details, leading to inaccurate avoided emissions estimates in specific use cases (see also Table 3). This trade-off complicates the ability to reflect real-world outcomes,

[2] "Traditional linear consumption practices" refer to the conventional approach to consumption where products are designed, manufactured, purchased, used, and then discarded as waste. This linear model follows a "take, make, dispose" pattern, in which resources are extracted (take), used to produce goods (make), and the products are ultimately thrown away after use (dispose), contributing to environmental degradation and resource depletion.

especially in uncertain future scenarios like circular economy strategies, where assumptions about technology, behaviour, and market dynamics can significantly impact results.

- **Baseline Scenarios:** Determining the appropriate baseline scenario (i.e., what would have happened without the circular intervention) is complex. For example, in the case of product reuse, the baseline could be the production of a new product, the disposal of the used product, or the continued use of the product in its current state. The choice of baseline significantly influences the calculation of avoided emissions.
- **Imperfect substitution**: Imperfect substitution refers to the fact that circular economy products or services may not perfectly replace their linear counterparts in terms of functionality, quality, or consumer acceptance. When a circular product does not fully substitute for a new product, the expected environmental benefits may be diminished. Additionally, if the circular product is less desirable or functional, consumers may end up purchasing additional products to compensate, leading to higher overall emissions.
- **Rebound effects**: Rebound effects occur when the environmental benefits anticipated from a circular economy strategy are partially or wholly offset by changes in behaviour or other market dynamics that lead to increased consumption. For instance, if the cost savings from using a refurbished product lead consumers to spend their savings on other goods or services that have their own environmental effects, the net environmental benefit may be reduced or even negated. This is particularly relevant in scenarios where the circular economy strategy leads to lower prices or increased availability of products, which can drive higher overall consumption.
- **Data Availability and Quality**: Circular economy strategies often involve innovative practices with limited historical and current data. The lack of reliable data on the environmental performance of these strategies can lead to uncertainties in LCA results.

Similar to LCA as a methodology, the quantification of avoided emissions can follow different standards or assumptions that are not always consistent with each other. This starts with the fact that the calculation of avoided emissions is related to multiple terms such as "system expansion", "handprinting", "Scope 4" or "substitution in attributional LCA" etc. Although they refer to the same principle, they have different nuances and requirements for scoping and allocation. Due to this lack of clarity, the World Business Council for Sustainable Development (WBCSD), as part of its Net-Zero Framework, has been working on a better understanding of avoided emissions in a corporate context and published a guidance on this in 2023 (WBCSD et al.). The guide provides a comprehensive and detailed overview and is recommended for all LCA practitioners and companies starting to engage with the quantification and reporting of avoided emissions.

The guidance also distinguishes between different levels of specificity in the scope of scenarios and outlines the potential trade-off between situational accuracy and representativeness of scenarios (see Table 3), which is also highly relevant to this study as individual user behaviour could be very different from the average population and it is therefore difficult to determine which scenario is best suited to communicate the potential avoided emissions associated with a particular business model. For example, it may be that the business model of device rental appeals only to a very specific target group of users, who would also behave differently from the average population in the reference and baseline scenarios. Therefore, to make a fair assessment of the potential avoided emissions related to the rental of devices, it is necessary to control for these differentiating factors in the baseline and reference scenarios. However, due to a lack of data and effort, it is not always possible to carry out that kind of detailed assessment, which often leads to a mixed scenario, where user-specific solutions (S1) are compared to market average reference scenarios (R3), which however is not always consistent and representative for a specific claim on avoided emissions.

*Table 3: Various layer of specificity to quantify avoided emissions empirically (Adopted from WBCSD et al. 2023, Table 4)**

L	Approach	Specificity	Description	
			Solution (S)	Reference (R)**
1	**User-specific**	**High** Recommended approach for specific solution assessments whenever data is accessible, and assessments remain feasible with a reasonable number of resources	Specific life cycle emissions of each solution sold. The company performs a detailed calculation for each solution, considering specific usage scenarios. Example: life cycle emissions of a specific secondhand smartphone sold by a company in Germany	Specific reference for each customer who uses a company's solution. The company performs a detailed calculation for each solution, with detailed knowledge of the context. Example: reference behavior that the owner of this specific device would have adopted instead.
2	**Company-specific**	**Medium** Recommended if the calculation of a solution's life cycle emissions or reference is too complex at the scale of each sale	Average life cycle emissions of a solution, specific to a company. The company performs a detailed calculation, considering a usage scenario by solution range and by market in which the solutions are sold. Example: average life cycle emissions of all secondhand smartphones of the same type sold by a company in Germany.	Average reference for a given company's solution sold in a given market. The company performs a detailed calculation, considering a reference scenario for each solution line and each market in which the solutions are sold. Example: reference behavior that a company's average customer would have adopted instead.
3	**Market-average**	**Low** Recommended for market averages and preliminary evaluations of avoided emissions	Average life cycle emissions of the solution in a given market. Note: In this approach, emissions are not specific to the company and can be standardized for a given type of solution in a given geography. Example: average life cycle of a secondhand smartphones sold in Germany	Average reference of the solution in a given market. Note: In this approach, the reference situation is not specific to the company and can therefore be standardized for a given solution in a given geography. Example: reference behavior that an average German smartphone owner would have adopted instead

* The examples in the table are not the original ones mentioned in the guidance.
** In this report reference scenarios are also called "baseline" Scenarios.

The following report will carry out mixed scenario analysis on different layers described above and is organized as described in Table 4:

Table 4: Overview on scenarios in this report and their specificity level according to WBCSD et al. 2023 (Table 5)

Analysis	Chapter	Solution	Reference / Baseline	Specificity level*
Market analysis on the general reuse of ICT devices in the Germany	Section 3	Re-use quote of ICT devices after use through circular business models	General flow of ICT devices after use	Low
Representative user-specific scenarios for two circular business models	Section 4	Lifecycle emissions for the re-use of smartphone, laptops, digital cameras and games consoles	Average lifecycle emissions through use and reuse of the device	Low

Analysis	Chapter	Solution	Reference / Baseline	Specificity level*
		through refurbishment and rental of devices on base of **average company data**	without the use of circular business models	
Guidance for company specific calculations for partners of the project	Section 4.3.3	Smartphone, laptops, digital cameras and games consoles through refurbishment and rental of devices on base of **specific company** average data	Average lifecycle emissions through use and reuse of the device without the use of circular business models	Medium-low

*Please note that the low specificity is not necessarily bad. The choice of the level of specificity depends on the nature of a solution sold and what the company wants to explore through its calculations.

3 Market average: Reuse of ICT devices in Germany

3.1 Goal and Scope

This section addressed the environmental impact of reuse of ICT devices at the market level. Although not the primary scope of this report, it is an important step to quantify the status quo in the market and derive key coefficients for the baseline scenario, that can be also use for the assessment of more business model scenarios (see section 4.2.4).

As briefly touched upon in section 2.1, specific data for all R-strategies that can extend the life of a product and thus avoid the need for additional primary production points in the same general direction: It is beneficial for the environment if the associated rebound effects are kept within limits (see section 2.2). However, studies still struggle to understand how electronic products flow through the economy and which paths they take after their first use. The judgment of the Global E-Waste Monitor is consistently sobering: while we know for certain that global e-waste is increasing, obtaining precise data is difficult due to a grey zone in business practices. Non-functional used electronics are often shipped for reuse, with individuals claiming that the electronics can still be repaired (Balde et al. 2022, no. 4). Currently, we have only a vague understanding and numbers of how many electronic products are resold for a second life, remain functional but unused in a drawer, are repaired, or end up directly in recycling or other dubious channels. Among other reasons, one problem is often that the information itself is fragmented and not always attainable in an aggregated way.

The following chapter will try to make an approximation on the current flow of electronic products through the German economy. The goal will be to give an answer on:

- The proportion of products that remain functional after their first use-phase
- General repair quota and success rates
- Re-use rate and second life options
- End of life rate

Displacement rate of primary products through second-hand devices

The analysis will specifically focus on consumers' after-use decisions. Understanding the exact causes and consequences of the after-use phase of devices plays a key role in their reuse. On one hand, the reasons for the end of use do not always stem from a defect in the device; on the other hand, the conclusion of initial use does not necessarily lead to disposal, as additional usage cycles may follow.

3.2 General assumptions

The analysis of flow of devices will circle around two general questions:

- **Q1 – Status quo**: What do people do when they stop using their old device?
- **Q2 – Effects on consumption**: What are the effects on the general consumption level of new devices (meaning number of new devices purchased) when people stop using their old devices?

For the initial analysis, a visual method inspired by Material Flow Analysis and Input-Output Analysis was employed to outline the potential pathways that devices can take within the economy. Based on this, the team first developed a Circular Stock Model, as illustrated in Figure 2, which provides a high-level analytical representation of the replacement and consumption of new products in the market through circular practices such as the repair and reuse of old products.

The model consists of an input and output side, along with multiple elements that illustrate temporary stocks where products remain for a certain period. It also includes flow rates that indicate how quickly products can transition from one temporary stock to another, as well as key decision points where the direction of a flow to the next temporary stock is determined.

The input of the stock model begins with consumers making decisions to consume either new or second-hand products. By simply assuming that consumption levels are fixed, second-hand products could displace the demand for and production of new products, which would be a key mechanism to avoid emissions and other related environmental impacts. After the products have remained in use for a certain period,

consumers eventually decide to stop using them, a point labelled in the model as "end of use" and "after-use."

After-use refers to the phase in a device's life cycle that begins once its initial use by a consumer has ended. This phase includes the decisions and actions taken by the consumer regarding the device, such as whether to dispose of, resell, recycle, donate, or repurpose it.

The after-use decision is a crucial junction where consumers determine how to proceed with their products. This decision could lead to three options:

- **Route A: Direct Reuse**
  The product could be directly reused by either selling, take-back schemes or gifting it to relatives, which has the potential to loop back and displace the input of new products into the consumption system.
- **Route B: Repair**
  If the product has a defect, it could be taken in for repair. This could result in a successful repair, allowing the product to return to reuse (Route A), or it could lead to the product reaching its end of life.
- **Route C: Reuse Resistance**
  Reuse resistance is a novel concept within the model, indicating that user put their products simply in a state of hibernation (e.g., stored in a drawer as a backup device) or dead storage (Wilson et al. 2017). This condition could potentially lead to reuse again (Route A) or directly to their end of life.

It is important to note that although the defect of a device may play a significant role as a contributing factor in explaining which route products take in the after-use phase, it is not a sufficient factor to determine whether products end up in Route B (repair) or Route C (reuse resistance). Other considerations, such as consumer attitudes, perceived value, and convenience, also influence these decisions.

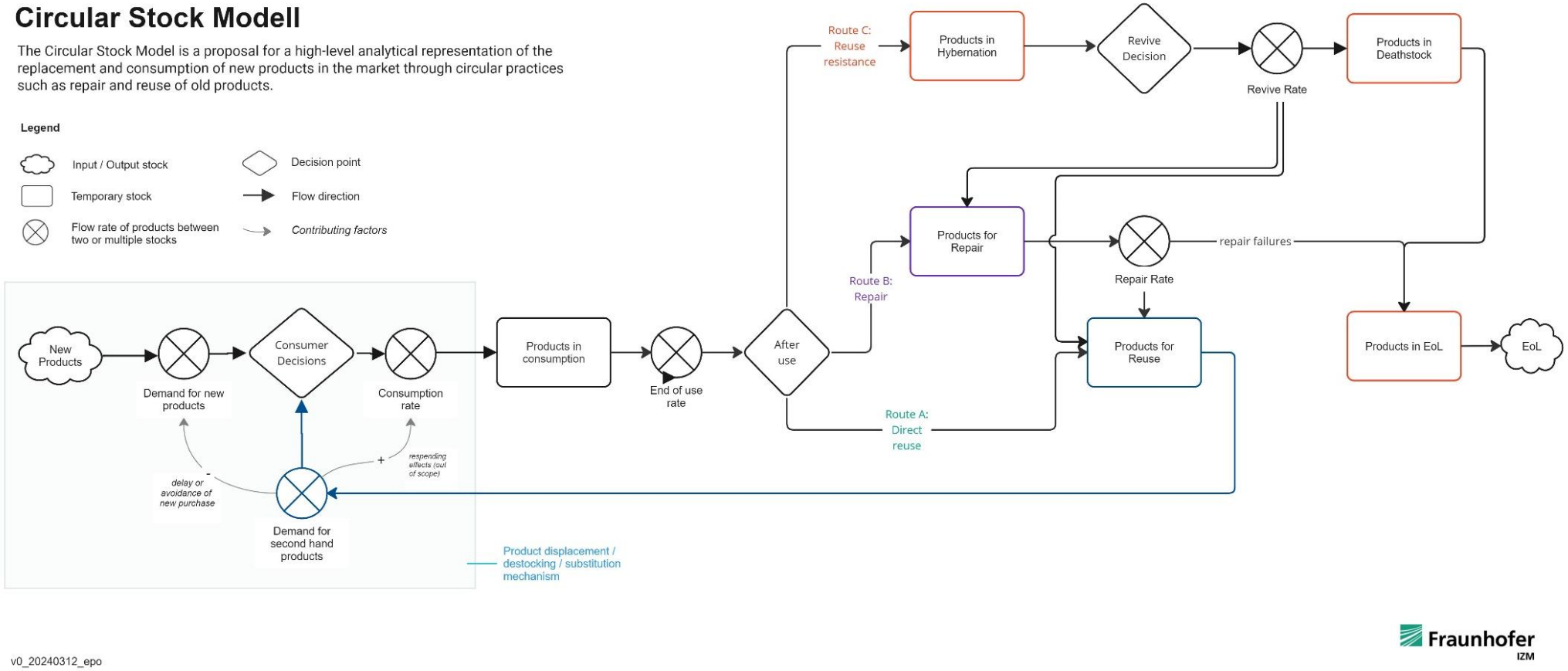

Figure 2: Circular stock model developed by the authors to determine the potential market wide savings through circular strategies

3.3 Data inventory

Building on the considerations above, secondary data research was conducted to address several coefficients outlined in the circular stock model. The primary objective was to gather market average data on ICT equipment consumption, focusing on obtaining more specific data for the targeted product groups. The findings are summarized in Table 5.

Table 5: Inventory and coefficients for the circular stock model

Category	Indicator	Value	Unit	Source
Demand for second hand products	Average use of second-hand devices	14	%	Circularity 2024
	Use of second-hand smartphones	14	%	
	Use of second-hand digital compact cameras	9	%	
	Use of second-hand Laptops	13	%	
	Use of second-hand Games consoles	17	%	
Reasons for device replacements	Defects	27	%	Poppe et al. 2022 on base of Eurobarometer 2020
	Other reasons	73	%	
	Defects of Smartphones	41	%	Poppe et al. 2022
	Defect of Digital compact cameras	26	%	
	Defects of Laptops	40	%	
	Defects of Games consoles	19	%	
Repair Rate	Average repair rate for 38 product groups	24	%	WERTGARANTIE 2022/2023
	Smartphone repair rate	27	%	
	Digital compact camera repair rate	35	%	
	Laptop repair rate	40	%	
	Games console repair rate	36	%	
Repair Success Rate	Repair success	91	%	APPLiA 2021
	Repair failures	9	%	
After-use decisions of customers for functioning devices	Reuse	45	%	Circularity 2024
	Gifting	8	%	
	Donating	6	%	
	Selling 2nd hand	23	%	
	Giving back to rental company	2	%	
	Trade in for new device	6	%	
	Additional consumption	7	%	
	Alternative usage	7	%	
	Hibernation	21	%	
	Keeping in drawer as backup	21	%	
	Miscellaneous	15	%	
	Don't know	10	%	
	Other	5	%	
	End of Life	12	%	
	Handing back to recycling	9	%	
	Tossing	3	%	
Displacement rate	Substitution quote of new devices through second-hand devices			Missing Data
	Additional device consumption through second-hand devices			

Unfortunately, the secondary data gathered does not allow for a consistent quantification of the proposed circular stock model, as outlined in Figure 2, and is subject to certain limitations. Data was obtained from multiple sources that differ in scope, reference period and their survey method.

The general demand for second-hand equipment compared to new equipment is based on a consumer survey conducted as part of this project (Circularity 2024). According to this, the average usage of second-hand equipment in Germany is 14%, which is in line with another study by WERTGARANTIE (2022/2023), which reports that the average number of products bought second-hand in Germany is 12%.

Defects, cited by 27% of respondents as average reason for replacing their old devices, are based on data from Eurobarometer 2020 and interpolations from Poppe et al. 2022. The low rate of replacement due to defects is also confirmed by WERTGARANTIE (2022/2023), which reports an average failure rate of 35% for electrical appliances within 10 years, although this can range from 10-100% depending on the product group. In addition, van den Berge, Magnier, and Mugge found in an independent premature obsolescence testing program that 60% of users replace their equipment without a defect. Product group-specific defects as reasons for replacing old equipment were obtained from a customer survey conducted by (Poppe et al. 2022).

General repair rates were obtained from a large consumer survey by WERTGARANTIE (2022/2023), which showed an average repair rate of 24% in the market and was also able to provide product group specific data. For all repairs executed, an average success rate of 91% could be assumed based on industry data from APPLiA 2021.

Data on the different after-use paths that products typically take were provided by the results of the Circularity e.V. consumer survey (Circularity 2024) and where clustered into different endpoints such reuse, additional consumption (second or third use), hibernation, miscellaneous, and end-of-life.

No direct data on the overall substitution effect or the scale of induced additional consumption is available. However, the Circularity consumer survey (2024) did include questions on accelerated replacement and increased purchasing behaviour. While it does not allow for quantifying the extent of additional purchases, it provides clear indications that both renting and buying second-hand can lead to shorter usage durations and additional device acquisitions for certain user groups (Circularity 2024). These behavioural patterns - indicative of potential rebound effects - are considered in one of the scenarios within the circular impact measurement.

3.4 Results

For the modelling, the coefficients from the data inventory were entered into a dynamic input-output equation, where the reference flow of the model is 1 product in after-use (1 = 100%). The coefficients were then added according to the circular stock model, the results of which are presented and discussed in the following sections for the average market and product group specific. The results are explicitly presented as regional approximations for the German market and do not claim to be fully representative.

The following sections are organized as follows: First the results of the market average for after-use of ICT equipment will be presented followed by the more product specific scenarios for smartphones, laptops, digital compact cameras and games consoles.

3.4.1 Sankey Chart after-use of ICT equipment

For better interpretation, the results of the input-output modelling were visualized using a Sankey diagram, as shown in Figure 3. The Sankey diagram illustrates the flow of devices between different stages before and after-use, with the width of the arrows proportional to the magnitude of the flow. In this case, it helps clearly depict the balance between the input and output of second-hand devices, making it easier to understand the distribution and movement within the system.

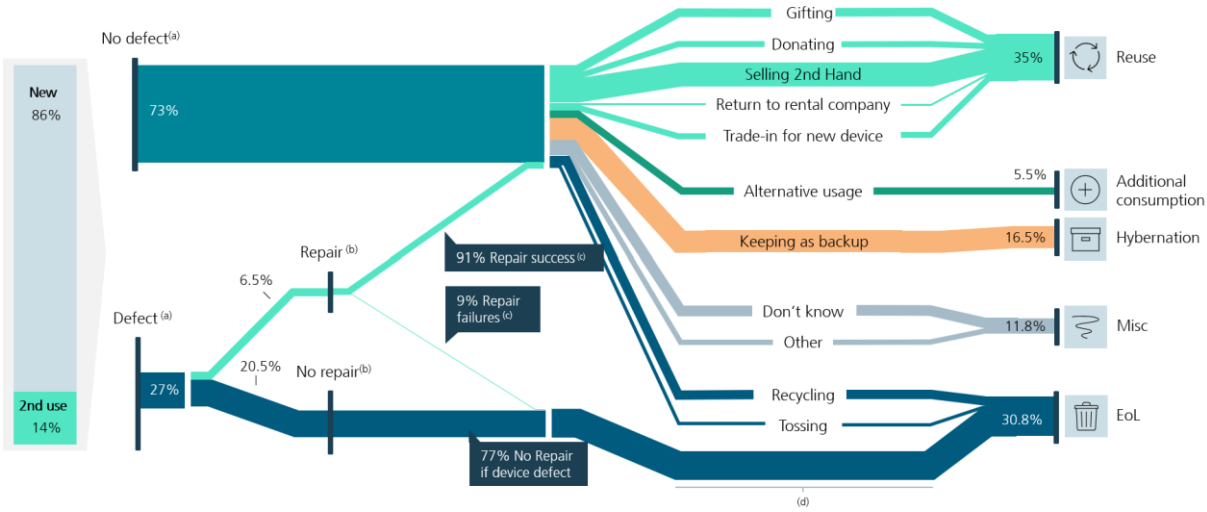

Figure 3: Approximated flow of ICT devices after-use in Germany (2020-2024) (Source: Fraunhofer IZM 2024)

The analysis highlights several key indicators regarding the flow of ICT equipment before and after use. Most devices before the after-use phase are new, making up 86% of the total, while 14% of devices are second-hand. Among the devices entering the after-use phase, 27% are being replaced due to defects, whereas 73% are still functional but are no longer used for other reasons. Overall, more than 35% of all devices are intended for reuse after-use, leading to a positive net-flow of second-hand devices. The net flow of second-hand devices serves as a circularity indicator that balances the input and output of these devices within an economic system. Essentially, it reveals whether more second-hand devices are entering or leaving the system. In this case, the results show that 22% more devices are leaving the system intended for reuse than are entering it. This positive net flow indicates that, within the considered market scope (Germany), more devices for reuse are leaving the system in after-use than being introduced as second-hand.

Approximately 18% of all devices are sold, while around 5% are traded in. Notably, only 30.8% of devices are recycled, according to the model. In contrast, 16.5% of devices are stored as backups, and 5.5% are set aside for alternative uses.

3.4.2 Key results for all product groups

The input-output analysis for the circular stock model was conducted for the market average of ICT equipment and on the targeted product groups such as smartphones (SP), laptops (LP), digital compact cameras (DC), and gaming consoles (GC). The key results of this analysis are presented in Table 6.

Table 6: Key coefficients for the after-use of ICT devices

Category	Indicator	ICT	SP	LP	DC	GC	Unit
Reference Flow		**1**	**1**	**1**	**1**	**1**	**Device in after-use**
Intended use duration*	New device	-	3.6	4.4	3.3	3.8	Yrs
	Second-hand device	-	3.6	3.9	2.9	3.7	Yrs
Before after-use	New devices before after-use	86	86	87	91	83	%
	Second-hand devices before after-use	14	14	13	9	17	%
	Defects before after-use	27	41	40	26	19	%
	No-defects before after-use	73	59	60	74	81	%
Repair	Repair of defect devices	24	24	40	35	36	%
	Successful repairs as share of all devices in after-use	5.9	9	14.6	8.3	6.2	%
After-use	Reuse	35.55	30.6	33.6	37	39.3	%
	Gifting	6.3	5.4	6	6.6	7	%
	Donating	4.7	4.1	4.5	4.9	5.2	%
	Selling 2nd hand	18.1	15.6	17.1	18.9	20.1	%

Category	Indicator	ICT	SP	LP	DC	GC	Unit
	Giving back to rental company	1.6	1.4	1.5	1.6	1.7	%
	Trade in for new device	4.7	4.1	4.5	4.9	5.2	%
	Additional consumption	5.5	4.8	5.2	5.8	6.1	%
	Alternative usage	5.5	4.8	5.2	5.8	6.1	%
	Hibernation	16.6	14.3	15.7	17.3	18.3	%
	Keeping in drawer as backup	16.6	14.3	15.7	17.3	18.3	%
	Miscellaneous	11.8	10.2	11.2	12.3	13.1	%
	Don't know	7.9	6.8	7.5	8.2	8.7	%
	Other	3.9	3.4	3.7	4.1	4.4	%
	End of Life	30.6	40.2	34.4	27.6	23.2	%
	Handing back to recycling	7.1	6.1	6.7	7.4	7.9	%
	Tossing	2.4	2	2.2	2.5	2.6	%
	Repair failures of defect devices	0.6	0.9	1.4	0.8	0.6	%
	No repair of defect devices	20.5	31.2	25.4	16.9	12.2	%
Net-Flow of Second-hand devices**	Input of Second-hand devices	14	14	13	9	17	%
	Output of Second-hand devices	35.55	30.6	33.6	37	39.3	%
	Net-flow of Second-hand devices	21.55	17	21	28	22	%

* Circularity 2024
** The net flow of second-hand devices is calculated by subtracting the (input) share of second-hand devices before the after-use phase from the (output) devices intended for reuse. Products intended for additional consumption or in hibernation are excluded from the net flow calculation due to their ambiguous status and their unclear potential to substitute new products on the market.

ICT = Average ICT-equipment, SP = Smartphones, LP = Laptops, DC = Digital Camera, GC = Games Consoles

The following key aspects summarize the findings across all product groups:

- **Second-Hand Use and positive Net-Flow**: Across all product categories, there is a consistent ratio of second-hand use before the after-use phase, ranging from 9% to 17%. Despite these relatively similar input levels, the output of devices intended for reuse is notably higher, varying between 30% and 40%. This leads to a positive net flow of second-hand devices in the output of the system, with a surplus of 17% to 28%. This surplus highlights the potential for increased circularity across all product groups, but also shows that demand for second-hand devices in Germany is 17% to 28% lower than the after-use supply in this region.
- **Defects and Repair Rates (Smartphones and Laptops)**: Both smartphones (SP) and laptops (LP) exhibit comparable defect rates before the after-use phase, each around 40%. However, a significant difference emerges in the repair rates: while only 24% of defective smartphones are repaired, laptops show a much higher repair rate of 40%. This suggests that laptops have a longer second life potential through repairs, whereas smartphones are more likely to be discarded or replaced after defect.
- **Gaming Consoles**: Gaming consoles (GC) present a unique profile, with a relatively low defect rate of 19% before after-use. Interestingly, if a defect does occur, games consoles have a high repair rate, with 36% of defective devices being repaired. This combination of low defects and high repair potential positions games consoles as one of the more durable product categories in the analysis

3.5 Discussion

The primary objective of this analysis was to address two key questions. First, it aimed to provide an overview of the current status of circularity in device usage and track consumers' after-use decisions, the results of which are presented in the two sections before. Second, it aimed to evaluate the potential effect on overall consumption levels if individuals stopped using their old devices. In relation to this question, the following

discussion will explore the robustness of the analysis, taking into account moderating factors such as product lifetimes, and will clarify the potential for second-hand devices to displace new products in the market.

To come straight to an important result, the difference in the use duration of new and old devices does not appear to have a major moderating effect on the supply and demand of second-hand devices. The consumer survey by Circularity e.V. (Circularity 2024) found out, that the intended usage duration of new and old devices shows minimal variation. Although the intended use duration often does not align with the actual product lifetime in practice (van den Berge, Magnier, and Mugge), it can be assumed that new and second-hand devices move through the system at a similar pace on average.

From a circular economy perspective, the figures above reveal a concerning imbalance: the use of second-hand devices in the German market remains relatively low (M=14%), even though most devices (73%) are still functional when consumers stop using them. When combining these non-defective devices with those successfully repaired (with a notably high success rate of 91%), approximately 79% of after-use devices remain potentially operational. Instead to reuse and resell, it seems many functional devices are kept as backups (16.6%), have an unknown status (11.8%), are used for additional consumption (5.5%) and even end up in recycling (9.5%). Although the functional quality of the intact after-use devices remains unknown, there is a gap of 43.5% between the intended reuse at 35.5%, indicating a potentially missed opportunity for product lifecycle extension through reuse. The reasons for this could be:

- Declining product quality: Even without technical defects, consumers often discontinue using products due to functional or symbolic obsolescence (van den Berge, Magnier, and Mugge). In the case of ICT devices, also software obsolescence could play an important role. Increasingly, empirical examples highlight how malfunctioning software, upcoming high-performance requirements, degrading software quality, or discontinued after-sale services can prematurely end the lifecycle of otherwise fully functional products (Jaeger-Erben et al. 2023).
- Declining consumer expectations: Independent of the device itself, research has identified additional mechanisms by which consumers can devalue older products in favor of new ones. New products are often perceived as more valuable than older or currently used items (Frick, Jaeger-Erben, and Hipp 2020). Marketing strategies further reinforce this perception by portraying new products as technologically superior, more convenient, and easier to use, which encourages early replacement or additional purchases (Poppe and Frick 2023).

Given the arguments above, and considering that not all second-hand devices meet the specific demands of consumers in the same region, it appears natural that there is an oversupply of second-hand devices after their first-use in the market. However, the question still remains as to where these unwanted but still functional devices will end up. Based on discussions and data within the project, it showed clearly that devices which cannot fulfil the specific needs of the German market are exported – directly, but also to a great extend in bulk. How many of these devices actually end up in reuse, where and for how long remained unclear, leading to a major uncertainty in the circular impact scenarios as described in section 4.

4 Circular Impact Measurement

4.1 Overview and motivation

The idea of the impact measurement within UNDRESS Circularity is to assess the performance of a specific business model regarding the impact of actual service life per device. This considers the activities needed to fulfil these business models, but most importantly the actual real-life effects on the service life in various life cycle phases.

Most current life cycle assessments focus on the production and end-of-life phase and the use phase is seen rather from the perspective of energy consumption than from the perspective of service life duration (Pohl et al. 2019). Service life is rather seen from the perspective of fixed assumption across studies or in PCRs (e.g. mobile ICT: 3 years, stationary devices: 5 years) or from the perspective of hardware durability discussion. The effects of real-life user behaviour are seldom considered.

This leads to the effect that when circular business models are analysed, their effect is also often compared to these standardized use phase assumptions rather than to existing market behaviour. The idea of this study and methodology is to shine light on real-life behaviour with and without circular business models for a fair transparent and realistic comparison.

The gap therefore was two sided:

- how to assess the impact of circular business models
- and to which scenarios should circular business models compare to

This study therefore did not only look at the formular development, but also on the data collection regarding current ICT use.

Many existing methodologies have a clear focus on reporting on company level and how to allocate emissions to individual companies along the value chain for ESG reporting and receiving funding, for example the CSRD (Corporate Sustainability Reporting Directive), ESRS E5 (European Sustainability Reporting Standards – Climate Change), and Circular Transition Indicators. However, from life cycle assessment perspective, the approach needs to differ. Additionally, interviews with company representatives clearly showed that potential benefit of the circular business models is not achieved by one company alone (Circularity 2025), but because many different actors work together along the value chain but also along the cascading use chain of the products. Therefore, assessing the potential benefit of the business model needs to address this chain rather than individual company impact - which might still be assessed for different purposes. Nevertheless, many data points which are already captured for company reporting – from energy consumption of operation processes to number of devices treated and sold – can and should be used also in the developed methodology.

Life cycle assessment and how the products are being used are key to understanding the drivers to the life cycle emissions and how to allocate resources better, seeing beyond the standardized product- and company-based carbon footprint.

Business models and companies providing circular offerings do not differ in the production and distribution of products but rather influence the use phase and therefore resource allocation, intending to avoid premature product replacement and production new products. There are limited guidelines, considering the benefits of prolonging a products lifespan, however it is unclear how circular business model actually perform in prolonging the lifespan of used products in real life conditions, also taking into account opposite rebound effects in user behaviour. Existing studies often consider a direct replacement of a new device through second-hand use and a longer initial use time in the rental period of the device. This leads to quite high – and based on user survey and associated partner data overestimation of potential benefits (Circularity 2024). Real word savings are lower as real-life service life extension through CBM is lower than just adding second-hand lifetime to average service life, not even taking into account rebound effects through potentially overall increased consumption patterns.

Furthermore, the carbon footprint allocation within the device life goes beyond country borders, therefore assessment along the whole lifecycle and device journey needs to be considered.

This is where the methodology and the developed scenarios try to capture findings from surveys, interviews and industry insights to more realistically assess and reflect how the product use phase within circular

business models versus the linear consumption model influence the carbon footprint. Additionally, the study attempts to capture that we are not starting from a purely linear market as repair and peer-to-peer pass-on of devices with re-use has been taking place for many years.

4.2 Methodology

The following sections describe the methodology, developed scenarios, and perspectives of analysis in detail. The main aspects are that

- The methodology captures relevant product and usage related emissions along the device lifespan from production to end-of-life.
- It takes into account multiple use phases, considering both the proportion of devices that are transferred and reused, as well as the duration of use in active utilization in each phase, depending on the perspective of analysis.
- By distributing the total emissions across these different life phases, an emission value based on actual usage data can be calculated for the device's real lifetime.

Throughout the study we will look at different scenarios regarding the different options how devices can be used. Thereby, we have different perspectives (device or business level) how to assess the impact. These scenarios, viewpoints and system boundaries are explained in this section, followed by a detailed description of the available and needed data in section 4.3 and case study results in section 4.4.

The methodology developed for this study aims to realistically assess the environmental impact of circular business models by focusing not only on the technical life cycle of devices but especially on their actual use across multiple life phases. By linking emissions across the entire value chain to the effective usage time of a product, the approach allows for an evaluation of how efficiently a device is used under different usage and business model scenarios.

In contrast to traditional life cycle assessments, which often rely on fixed assumptions about service life, this approach incorporates real-world behavioural data on how often, how intensively and how long products are used. It includes scenarios such as device rental, resale, peer-to-peer exchange, and reuse following refurbishment or repair. Each of these scenarios is mapped in full – from production and first use, through all subsequent use phases, up to end-of-life treatment.

The central metric used to evaluate environmental performance is the Global Warming Potential per year of active use. This metric quantifies the total climate impact of a device (in CO_2 equivalents) in relation to its actual service delivery over time (meaning days when the device is actually used in comparison to the calendar time during which a device is used infrequently). In addition, the model produces key indicators such as the total active use time and the total life cycle GWP per scenario, enabling meaningful comparisons between circular and linear models.

An important factor across all scenarios is the total active use duration of devices, which significantly influences the calculated GWP. It is inherently critical both for the total GWP and for the GWP per year of use, particularly through energy consumption during the use phase. In this context, the active use duration serves as the *denominator* in the calculation of GWP per year, while the various impact categories such as transport emissions, use phase energy consumption, and refurbishment emissions represent the *numerator* of the formula. Longer active use periods spread the production-related and repair or refurbishment emissions over more years and reduce the relative environmental burden per year, highlighting the importance of extending product lifespans within circular business models

Each scenario combines a specific business model, product type, and user group. At minimum, a linear baseline scenario is defined for comparison purposes. Circular scenarios reflect business models such as renting or second-hand resale. In the context of consumer electronics, rental refers to the temporary provision of a device to users for a defined period, often through subscription-based or pay-per-use services. This model allows multiple users to sequentially use the same device, potentially extending its total service life. Second-hand resale refers to professional resale, which includes activities such as refurbishment and repair, enabling devices to be resold and reused. In the following, we will refer to the second-hand resale scenarios also as reuse scenarios.

The modelling approach uses one device as 100%, reflecting lower percentages along the different use phases to reflect the real-world fate of devices (e.g., share entering reuse, repair, or disposal pathways), based on survey data, company insights, and expert assumptions.

Due to the opaque nature of device flows – especially at the end of life or in undocumented exports – some gaps remain, which are addressed through transparent modelling assumptions.

All life cycle stages are assigned corresponding GWP values, from manufacturing and logistics to usage-related energy consumption, refurbishing processes, and final disposal. Usage intensity is differentiated by device type – for instance, smartphones are used more frequently than gaming consoles – and all devices are assumed to go through similar manufacturing and end-of-life processes, allowing for the impact of circularity to be isolated to the use phase and reuse patterns.

The methodology ultimately provides two main outputs (see Figure 4):

- Total GWP across the device's entire life cycle
- Total active use time, reflecting extended lifespans achieved through circular strategies

These outputs result in GWP per year of use respective GWP per active use, showing how extensive the device was used.

Together, these metrics allow for a data-driven, realistic assessment of how circular business models impact environmental outcomes – especially in terms of their ability to reduce emissions by extending service life and avoiding unnecessary production. Further details on system boundaries and scenario design are discussed in the following chapters.

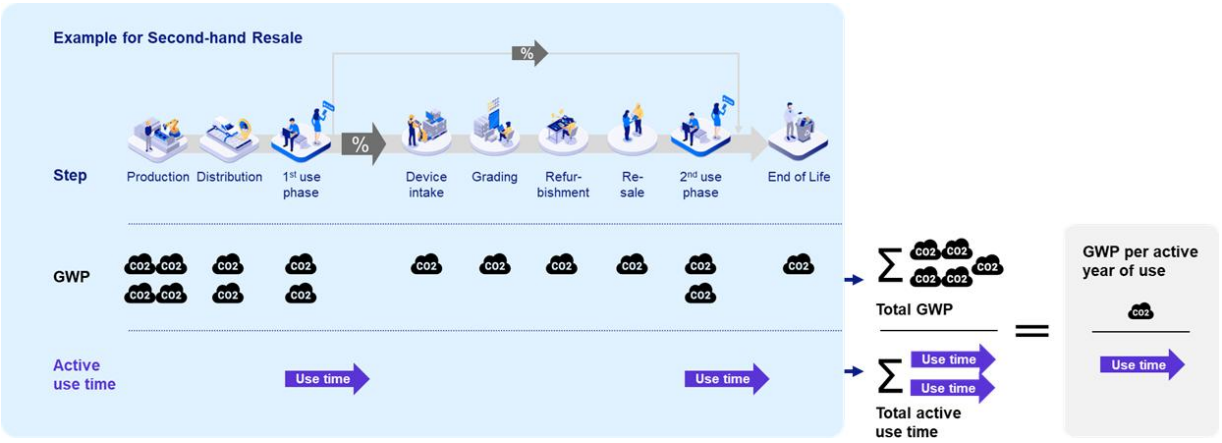

Figure 4: Business model life cycle assessment main outputs (Circularity 2025)

4.2.1 Product scope

As explained earlier, the focus of the study is on smartphones, laptops, digital cameras and gaming consoles.

In this study, frequently used products refer to those that are used regularly or almost every day, often integrated into daily life over long periods of time. Smartphones and laptops are examples of frequently used products, as they are commonly used on a daily basis. Infrequently used products are characterized by irregular usage patterns, typically limited to specific contexts or time periods. Such products, including digital cameras and gaming consoles, are predominantly used during particular occasions, such as vacations or designated leisure activities, rather than as part of routine daily use. The survey results collected within the framework of the study (Circularity 2024) were used to estimate the days of active use for each product type.

Additionally, it is important to clarify that frequent use does not equate to regular use. For example, digital cameras and game consoles may be frequently used during specific events, such as holidays, but they are not regularly used in daily life. This offers the unique potential for renting models, making the device available to several users, for example, during a holiday season. This distinction is crucial for the correct interpretation of the study's findings.

It is also important to note that this study focuses on the use of one device per person, rather than considering multiple devices owned by a single individual. In the case of products like digital cameras and

game consoles, it is assumed that there is one device per household. For laptops, while the study acknowledges that they can sometimes be shared among multiple people, the primary focus will be on individual usage rather than the combined use within a household.

The report will primarily focus on smartphones to explain the mechanisms of the formula and the effects on the results. For some aspects, game consoles will be used as an example to illustrate the dynamics of infrequently used products. Results for the other products can be found in the annex (chapter 6).

4.2.2 System boundaries

The impact assessment focuses on the category of climate change, using the global warming potential as the primary indicator. The methodology is, however, in general adaptable to other impact categories and indicators as well.

The formular to calculate the impact takes into account the following main aspects as fixed parameter across the different scenarios:

- GWP of manufacturing per device incl. transports within manufacturing and raw material acquisition
- GWP of transportation during manufacturing and end-of-life
- GWP of end-of-life treatment per device (without considering recycling benefits)
- GWP per use time or use-intensity related to energy consumption in use

Additionally, scenario dependent factors are considering:

- GWP of transport needed to enable the different use options and phases
- GWP of actions required to enable the different use options (e.g. device handling and storing, cleaning and data deletion, repair incl. spare sparts, additional packaging and accessories)
- Service life in different use phases (duration of first and second use, number and duration of rental cycles, active use days, etc.)

4.2.3 Perspective

The analytical framework is structured across three levels – product, business model, and market – to enable a comprehensive understanding of the environmental impacts of ICT device usage under circular business models. Each level offers distinct insights and serves specific methodological purposes (see Figure 5).

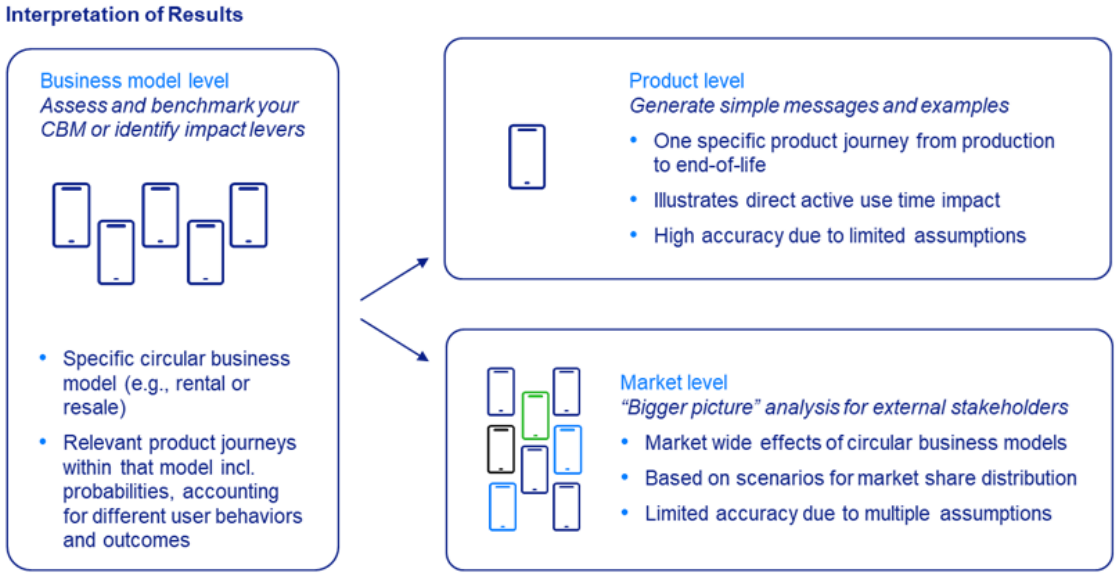

Figure 5: Interpretation of results in three levels (Circularity 2025)

At the **product level**, the analysis traces an individual device across its entire life cycle, from production to end-of-life. This micro-level perspective enables the highest degree of data precision by following concrete use cases. For instance, a smartphone may be monitored as it is initially purchased by a private user, subsequently transferred to a second user, and ultimately disposed of. This approach facilitates detailed calculations concerning device lifespan, active usage duration, and associated environmental impacts. However, this level of analysis is not suited for making generalizable claims about broader user groups or business model archetypes. Device-specific scenarios are modelled at a 100% probability, with defined archetypes representing typical product life cycles. These include: (1) linear use (single-user before disposal), (2) peer-to-peer transfer (informal handover between private users), (3) second-hand sales involving professional refurbishment, and (4) rental models with multiple usage cycles prior to end-of-life. These archetypes are analysed for both frequently used devices (e.g., smartphones) and infrequently used devices (e.g., gaming consoles), across both private and business use contexts.

At the **business model level**, the analysis aggregates usage behaviour across a group of users following a common usage pathway, such as rental or reuse models. While individual devices are not tracked, this meso-level perspective captures group-level behavioural patterns, including average durations of first and subsequent use phases and the proportion of devices passed on and reused after initial usage. These variables are combined to compute a weighted total usage duration that represents the overall performance of the business model in question. For example, a laptop rental model in Germany may be characterized by an average of 1.5 rental cycles lasting 18 months each, followed by 4 years of private use. This approach enables evaluation of business model performance under real-world conditions using market research, consumer surveys, and partner data. Various scenarios are modelled across both frequently and infrequently used devices, incorporating private and business consumer segments. Scenarios include linear use, peer-to-peer exchange, professional resale, and device rental.

At the **market level**, the analysis considers the overall distribution and penetration of different business models across the national market, in this case Germany. By applying relative market shares and corresponding average usage durations for each model, an estimate of the cumulative environmental impact – particularly global warming potential – can be derived. Although this macro-level analysis involves greater uncertainty due to variable device flows and usage behaviours and limited knowledge on international in- an outflow of devices, it allows for simulation of systemic trends. For instance, shifts in market shares between linear, second-hand, and rental models are used to project changes in average use-phase durations and associated emissions. Three market scenarios: (1) a purely linear consumption baseline, (2) the current market composition, and (3) an optimistic scenario assuming increased adoption of circular business models are assessed with the model. In each case, the Global Warming Potential is calculated by considering stable device flow rates and consistent average usage durations across time.

In conclusion, the multi-level approach – spanning individual product journeys, aggregated business model pathways, and market-wide dynamics – enables a nuanced assessment of the environmental implications of circular business models. By integrating these three analytical lenses, the study delivers a holistic understanding of how different usage patterns and market structures influence the overall carbon footprint of ICT devices.

4.2.4 Scenarios

In the course of the analysis, a range of scenarios was defined to reflect the different circular business models under consideration and their relevance across various product groups. The scenarios are structured to allow for a comparison between different forms of device usage, including a linear baseline, current market conditions, rental models, and reuse. Each scenario is applied to all four product groups – smartphones, laptops, digital cameras, and game consoles – and, where relevant, further differentiated by private and business use.

Figure 6 schematically illustrates different usage scenarios. The length of the arrows represents possible durations of use phases; however, these lengths should not be interpreted as exact or proportional indicators. This is particularly relevant because the graphic combines scenarios across four different device types, and not all elements apply equally to each type. In our specific case, we consider only two use phases and the potential for export.

The **linear baseline scenario** represents a conventional consumption model. In this case, a device is manufactured, used by a single user during the first use phase, and then discarded without being passed on. The environmental impact is calculated based solely on this initial use.

The **baseline market scenario** acknowledges that a portion of devices today already enter a second use phase – often through informal peer-to-peer transfer or resale. In this scenario, a realistic share of devices is assumed to undergo repair or refurbishment (including the associated transport emissions) before being used again. This means both the energy consumption of the first and second use phases, as well as emissions from potential repair processes, are considered. It serves as a middle ground between a purely linear model and fully structured circular business models, and represents more closely today's status quo in the German market without the commercialized second-hand market.

The **reuse scenario** expands further upon this idea. Here, devices are actively channeled into professional second-hand systems after the initial use phase. A share of products undergoes refurbishment, including potential repairs and transportation between actors, before being resold and used again. The environmental impact includes emissions from these processes as well as energy consumption during the second use phase.

The **rental scenario** introduces an additional layer of complexity. Devices are assumed to go through multiple rental cycles during the first use phase. Each cycle includes energy consumption as well as refurbishment, potential repair and transport between users. After the rental period, a portion of devices may still enter the second use phase, similar to the recommerce model. This scenario captures the cumulative effects of short-term multi-user access combined with extended use through resale.

Through these scenario definitions, the study enables a detailed comparison of environmental impacts across different product groups and business models, providing insights into the specific mechanisms and leverage points for reducing emissions in the use phase of ICT products.

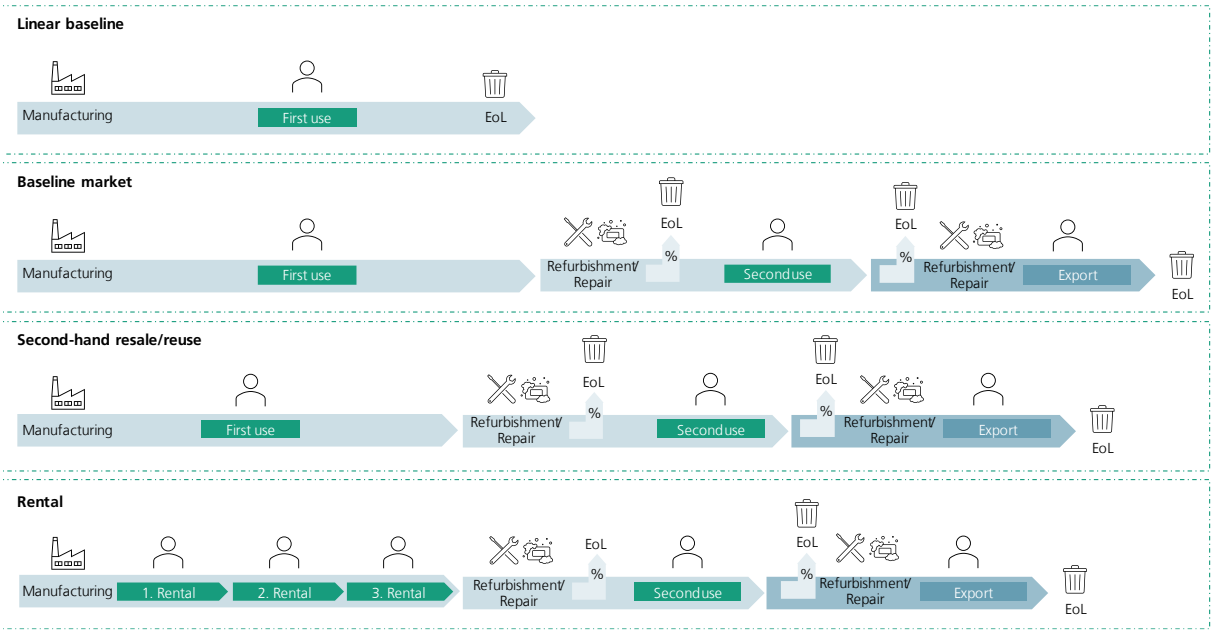

Figure 6: Scenarios

4.2.4.1 Linear baseline scenario

The reference scenario represents a purely linear consumption model. A device is used by a single user and then discarded without entering a second use phase. No repair or refurbishment is considered. The environmental impact is based solely on production-related emissions and energy consumption during the initial use phase. The individual terms and variables of the formula are explained below. Chapter 4.3.2 offers a more detailed examination of the influencing factors, drawing on specific data and assumptions.

$$GWP_{LinearBase} = GWP_M + GWP_{T1} + GWP_{U1} + GWP_{EoL}$$

$$GWP_M = \text{GWP of the Manufacturing}$$

$$GWP_{T1} = \text{GWP of Transport during manufacturing, distribution and EoL}$$

$$GWP_{U1} = \text{GWP of the First Use Phase}$$

$$GWP_{EoL} = \text{GWP of End of Life (Recycling)}$$

GWP_M:

Includes the total greenhouse gas emissions associated with the manufacturing process, expressed as CO_2 equivalents. The cradle-to-gate approach refers to the environmental impact from the extraction of raw materials (cradle) through to the point the product leaves the factory (gate), excluding its use phase or end-of-life. For consumer electronics this includes the mining and processing of metals like lithium, cobalt, and rare earth elements, as well as the energy and resources used in assembly, packaging, and transportation up to the factory exit. Accessories (e.g. charger), packaging and documentation are also included.

GWP_{T1}:

GWP of transportation, after leaving the factory, refers to the greenhouse gas emissions generated during the distribution and delivery phases. This includes emissions from transporting finished goods to retailers or directly to consumers. The GWP depends on factors such as the mode of transport (air, sea, or land), the distance travelled, and the efficiency of the logistics chain. Air freight typically has the highest GWP, while sea and road transport have a lower but still significant effect.

GWP_{U1}:

To assess the GWP for the usage phase of consumer electronics, it is essential to consider the energy consumption during the period the device is in use. This is influenced by factors such as the average battery capacity (for portable devices), the number of times the device is fully charged during the usage period, and the average energy loss during charging and operation. Additionally, the GWP of the power mix (i.e., the environmental impact of the electricity sources used) and the duration of the use phase should be considered. Accurate data on device performance, energy consumption patterns, and energy efficiency are crucial for a reliable GWP assessment during the usage phase of consumer electronics.

For infrequently used products, the "Active Days of Use" have a particularly significant effect, as energy consumption is much higher the active use of the device, making energy demand considerably higher on those days, compared to low standby consumption during non-active use.

GWP_{EoL}:

To calculate the GWP for the end-of-life phase of consumer electronics, particularly during recycling, several factors must be considered. These include the energy consumption associated with the recycling process, the emissions from waste treatment (such as dismantling and material separation), and the efficiency of recycling methods used. The type and amount of materials recovered (e.g., metals, plastics, and rare earth elements) also play a role in reducing the overall GWP. Additionally, the transportation emissions from moving the electronic waste to recycling facilities and any emissions associated with the disposal of non-recyclable components should be accounted for.

GWP_M and GWP_{EoL} as well as energy emission factors (as multiplicators for the energy consumption) during the use phase are treated as fixed values across the different scenarios.

4.2.4.2 Baseline market scenario

This scenario aims to reflect the current real-world market behaviour without professionalized recommerce. A portion of devices already enters a second use phase after their initial use – through peer-to-peer transfers or informal resale. Where a second use occurs, occasional repair or refurbishment activities are also considered, including associated transport emissions where applicable. This represents a realistic starting point for comparison with structured circular models. In this scenario, terms for repair and refurbishment activities are added, as well as a second use phase.

$$\boldsymbol{GWP_{Base_{market}} = GWP_M + GWP_{T1} + GWP_{U1} + x\% * \left(GWP_{T2} + GWP_{Rep} + GWP_{U2}\right) + GWP_{EoL}}$$

$$\boldsymbol{GWP_{T1}, GWP_{T2} = \text{GWP of Transport during Lifetime}}$$

$$\boldsymbol{GWP_{Rep} = \text{GWP of Repair Activities}}$$

$$\boldsymbol{GWP_{Ref} = \text{GWP of Refurbishment Activities}}$$

$$\boldsymbol{GWP_{U2} = \text{GWP of the Second Use Phase}}$$

GWP_{T2}:

GWP of transportation during the second use phase refers to the greenhouse gas emissions generated when a device is redistributed after its initial use. This includes emissions from collection, possible refurbishment logistics, and delivery to the second user. GWP_{T2} considers different transport routes than GWP_{T1}. Together with GWP_{T1}, GWP_{T2} accounts for the total transport-related emissions across the entire lifecycle of the device.

GWP_{Rep}:

Repair and refurbishment refer to measures aimed at extending the functional and economic life of electronic devices beyond their initial use phase. Repair typically involves the replacement or restoration of defective components – such as screens, batteries, or internal electronics – to restore basic functionality. Refurbishment goes beyond repair and includes cleaning, cosmetic improvements, technical checks, and in some cases, upgrades or replacement of functional parts. The goal is to return the device to a condition suitable for reuse or resale.

The GWP associated with these processes includes emissions resulting from the energy required for diagnostics, disassembly, repair or refurbishment, and quality control. Additional emissions can arise from logistics, such as the transport of devices to and from repair/refurbishment centers, as well as the production and transport of replacement parts and packaging materials.

GWP_{U2}:

To assess the GWP for the second use phase of consumer electronics, the same key factors as in the first use phase are considered, including energy consumption, battery capacity, charging cycles, and energy losses. However, it is important to acknowledge that, despite being the same device, both the duration of the use phase and the country of use can differ. These variations can affect the GWP due to differences in energy consumption patterns and the carbon intensity of the local electricity mix, as each region has a distinct electricity mix. A reliable assessment requires accurate data on energy consumption patterns, device efficiency, and the local electricity mix, which can be derived from literature, supplier data, and informed assumptions. In this study, reuse (like initial use) is considered to take place in Germany.

x%:

The factor describes the share of devices entering the second use phase.

4.2.4.3 Second-hand resale/reuse scenario

In this scenario, devices are intentionally collected and refurbished by professional providers after the first use phase. A defined share of devices undergoes repair and refurbishment before being resold for further use. The scenario includes energy consumption for both use phases as well as emissions from transport and refurbishment processes.

$$GWP_{Reuse} = GWP_{M} + GWP_{T1} + GWP_{U1} + x\% * \left(GWP_{T2} + GWP_{Rep} + GWP_{Ref} + GWP_{U2}\right) + GWP_{EoL}$$

$$GWP_{Ref} = \text{GWP of Refurbishment Activities}$$

GWP_{Ref}:

Repair and refurbishment refer to measures aimed at extending the functional and economic life of electronic devices beyond their initial use phase. Repair typically involves the replacement or restoration of defective components – such as screens, batteries, or internal electronics – to restore basic functionality. Refurbishment goes beyond repair and includes cleaning, cosmetic improvements, technical checks, and in some cases, upgrades or replacement of functional parts. The goal is to return the device to a condition suitable for reuse or resale.

The GWP associated with these processes includes emissions resulting from the energy required for diagnostics, disassembly, repair or refurbishment, quality control and the production of spare parts. In terms of professional repair and refurbishment, spare parts may also be harvested from other devices which are not fit for reuse anymore. This reduces the needed production effort for spare parts and can thereby reduce the associated GWP of repair processes. Additional emissions can arise from logistics, such as the transport of devices to and from repair/refurbishment centers, as well as the production and transport of replacement parts and packaging materials.

4.2.4.4 Rental scenario

This scenario models multiple intermediate rental cycles during the initial use phase, followed by potential resale and reuse. Each rental cycle involves energy consumption, and possibly refurbishment and transport between users. After the rental period, devices may be refurbished again before entering a second use phase.

$$\boldsymbol{GWP_{Rental} = GWP_M + \sum_{n=1}^{m}(GWP_{T_Rn} + GWP_{U_Rn}) + x * \left(GWP_{T2} + GWP_{Rep} + GWP_{Ref} + GWP_{U2}\right) + GWP_EoL}$$

GWP_{U_Rn}:

In this scenario, a rental model is considered, which introduces additional factors that must be taken into account when assessing the GWP of the usage phase. As a result, factors such as the number of rental cycles, user behaviour across different rental periods, and maintenance requirements may influence the overall energy consumption and device performance during the use phase.

The assessment of the GWP during the use phase within rental models is based on operational data provided by rental companies or partners, complemented by relevant literature and well-founded assumptions, without allowing conclusions to be drawn about company data.

GWP_{T_Rn}:

In the context of a rental model, transportation-related GWP includes not only the initial delivery from the manufacturer but also additional transport processes between the service provider and successive renters. These repeated logistics operations – such as shipping devices to and from customers for each rental cycle – can increase the overall transport-related emissions. The extent of this effect depends on the number of rental cycles, the distance between users and service hubs, and the chosen modes of transport, but also on the type – and thereby weight – of the device. As such, transportation within rental systems represents a distinct emission source that must be considered in GWP assessments.

To assess the transport-related GWP within rental models, primary data from rental companies, or their partners, is used wherever available. In addition, literature sources and context-specific assumptions can be applied.

GWP_{Ref}:

Repair and refurbishment refer to measures aimed at extending the functional and economic life of electronic devices beyond their initial use phase as described above. In terms of rental services, this specifically also covers data deletion and cleaning processes between rental cycles.

4.3 Data input and availability

4.3.1 Data collection

Since the underlying methodology is industry-agnostic by design, it requires the input of context-specific data depending on the sector, product group, and user behaviour. Broadly speaking, two types of information are essential: technical data on products, logistics, business processes, and end-of-life treatment, and behavioural data related to how the products are actually used. The latter has a particularly strong influence on the results of the analysis.

Much of the technical data required for the assessment, including emissions associated with product manufacturing, transportation logistics, energy consumption during usage, and end-of-life disposal or recycling, can generally be sourced from existing LCAs conducted by companies, research or other internal documentation. For this study, data was obtained from publicly available LCA studies, supplier-specific information, relevant academic literature, and confidential data provided by project partners. The confidential data from these partners was pivotal in forming the assumptions utilized in the analysis, but at the same time generalized to avoid drawing conclusions about company data. In addition, data from the previously mentioned consumer survey on usage patterns and behaviours (Circularity 2024) were integrated into the model to further enhance its empirical foundation.

The most critical and challenging data, however, relates to the actual use of devices in real life. This includes how long and how intensively products are used, what happens to them afterward, and whether and how

they are passed on for further use. These behavioural insights are typically not captured in company systems and must often be gathered through market research, user surveys, or scenario-specific assumptions. Key aspects such as early device failure, concurrent use of multiple devices, or second-hand usage significantly influence the overall assessment.

As part of the UNDRESS Circularity study (Circularity 2024), a consumer survey was conducted in the German market to gain a deeper understanding of real-world usage patterns and potential rebound effects. While such detailed research is not strictly required, a sound understanding of consumer behaviour is highly recommended for designing or evaluating circular business models.

In cases where no direct data is available – such as for second or third use cycles in international contexts – carefully considered and realistic assumptions must be made. To capture the full range of possible outcomes, scenario analysis can be used to explore variations in key parameters.

A consistent and adaptable methodology is built upon a foundation of reliable technical data coupled with realistic usage assumptions. For detailed guidance on how to gather and apply such data within a company context, refer to the section on "Company-Specific Adaptation of the Scenarios" (see section 4.3.3).

4.3.2 Study-specific assumptions across the scenarios

The scenarios in this study are based on representative standard products that serve as illustrative examples, rather than exact reproductions of specific, commercially available models. Instead, they represent typical characteristics and use patterns commonly found in each product category. As such, the goal of the model is not to deliver precise GWP values for individual devices, but rather to compare the relative environmental impacts of different circular business scenarios and highlight the influence of varying use behaviours.

The reliability of the assumptions used throughout the study depends significantly on the availability and quality of existing data. Where robust and representative data was available – whether from internal sources, literature, or partner contributions – it was applied. In cases where such data was missing or limited, reasonable and transparent assumptions were made, with care taken not to overstate or underestimate key effects.

The specific assumptions used along the product life cycle – across the different scenarios and product types – are summarized in the following sections. Any data gaps or uncertainties are clearly indicated and discussed to ensure transparency and support the interpretation of results. Thereby, the specific assumptions within the scenarios differ in some aspects from the scenarios in the industry report (Circularity 2025) to indicate more clearly potential effects of device exports in the reuse phase. Additionally, three scenarios with varying rental durations are set up to show the effects of this parameter and reflect the differences in existing services.

4.3.2.1 Smartphones

The following section presents the specific assumptions and data sources used to calculate the Global Warming Potential for smartphones, including all relevant life cycle phases – production, transport, use, and end-of-life. For each term, key input parameters and their respective sources are described, along with a brief discussion of data quality and potential uncertainties. Among the four product categories analysed, smartphones benefit from the most robust data availability.

4.3.2.1.1 Manufacturing

To assess the Global Warming Potential (GWP) associated with the manufacturing phase of a smartphone, a standardized set of assumptions was applied consistently across all scenarios to ensure comparability. The calculation is based on values from scientific literature, complemented by own assumptions. The scope includes the production of the smartphone itself, the charger, product and transport packaging, as well as user documentation. An overview of the respective parameters and data sources is provided in Table 7.

The manufacturing GWP of the smartphone (excluding accessories) is assumed to be 55 kg CO_2eq, based on Clement et al., which aligns with commonly cited LCA values for average smartphones. For the charger, a GWP of 1.94 kg CO_2eq is applied, derived from Fairphone 4-specific data (Sánchez, Proske, and Baur 2022). While other sources (e.g., (Poppe et al. 2024) report higher values (up to 4.96 kg CO_2eq for battery/charger/adapter), the Fairphone 4 value was selected due to its transparency.

Packaging-related emissions were calculated separately for the product box and transport box, using weight data from Ercan et al.. and emission factors for cardboard materials (0.262 kg CO_2eq/kg) from Print.de

(print.de 2023). The product box was assumed to weigh 0.074 kg, and the transport box 0.066 kg. The documentation, included as printed material (0.48 g), was assigned a specific GWP of 0.0142 kg CO_2eq/kg based on data from (Umweltbundesamt 2023). Product weight was considered to calculate transport emissions.

The resulting GWP for manufacturing all included components sums up to approximately 56.98 kg CO_2eq per smartphone unit.

While these assumptions provide a consistent basis for comparison across different scenarios, it is important to recognize that the manufacturing GWP may vary significantly depending on several influencing factors:

- Device specifications and hardware complexity, such as additional components or larger displays, can increase material and energy demand.
- Material composition, particularly the proportion of metals (e.g., lithium, cobalt, rare earths) versus plastics or bio-based materials, strongly affects emission levels.
- Production energy mix, with higher emissions arising from fossil-fuel-based electricity used in many electronics manufacturing regions (e.g., Southeast Asia).
- Supply chain structure, including the number of tiers and geographic dispersion of suppliers, can contribute to upstream emissions.
- Manufacturing efficiency, e.g., yield rates, process optimization, and scrap levels, influence the overall carbon intensity.
- Accessory and packaging design, especially the presence or absence of chargers and the use of minimal or recycled packaging, further alter the manufacturing footprint.

Given these factors, GWP values from literature or case studies must always be interpreted in the context of their methodological boundaries and assumptions. The values used in this model represent average estimates and serve primarily as a consistent reference point for comparative scenario analysis.

Table 7: Smartphone parameters manufacturing (for all smartphone scenarios)

Category	Parameter	Unit	Value	GWP (kg CO_2eq)
Smartphone	Manufacturing GWP	kg CO_2eq	55	55,0
	Average Weight	kg	0.15	
Charger	Manufacturing GWP	kg CO_2eq/ kg	1.94	1,94
	Average Weight	kg	0.071	
Packaging	Product Box Weight	kg	0.074	0,04
	Product Box Material GWP	kg CO_2eq/ kg	0.262	
	Transport Box Weight	kg	0.066	
	Transport Box Material GWP	kg CO_2eq/ kg	0.262	
Extra	Documentation Weight	kg	0.00048	7E-06
	Documentation GWP	kg CO_2eq/ kg	0.0142	
GWP Manufacturing		kg	0.36	56,98

4.3.2.1.2 Transport

In the following sections, the greenhouse gas emissions associated with different transport stages throughout the smartphone's life cycle are quantified. Each stage – from manufacturing to end-user delivery, and further to potential second use – is modelled separately to capture the specific characteristics and assumptions relevant to each scenario. The calculations are based on standardized distances, product weights, and transport-specific emission factors, while also highlighting where scenario-specific variations may occur.

Transport from Manufacturer to Seller

In this model, a consistent and realistic logistics pathway is assumed for all smartphone scenarios: the devices are manufactured in China (e.g., Shanghai) and delivered to a seller based in Germany (e.g., Düsseldorf). The transport chain includes an intercontinental shipment by air freight from Shanghai to Amsterdam, followed by inland distribution by truck from Amsterdam to Düsseldorf.

The calculation of transport-related GHG emissions is based on the total product weight and the distance covered, using the concept of *payload distance* (expressed in kilogram-kilometres, kgkm). This metric reflects the product of the transported mass and the transport distance and is a standard unit in logistics-related emission modelling. Emission factors are applied according to the transport mode and represent the average GWP per transported kilogram per kilometre.

For the air freight leg, a distance of 8,860 km is assumed, following the Fairphone 2 LCA (Proske, Clemm, and Richter 2016). With a ready-to-ship product weight of 0.361 kg (including smartphone, charger, product and transport packaging, and documentation), this results in a payload distance of 3,202.71 kgkm. Using an emission factor of 0.0005 kg CO_2eq/kgkm, the associated GWP amounts to approximately 1.60 kg CO_2eq per unit.

For the second transport by road, 250 km from the port in Amsterdam to the retailer's distribution center in Düsseldorf is assumed. The resulting payload distance of 90.25 kgkm, combined with an emission factor of 0.000118 kg CO_2eq/kgkm (VDE dialog 2023) yields additional emissions of 0.01 kg CO_2eq per unit. In this scenario, sea freight is not considered, as air transport is assumed to be the preferred method due to time-to-market pressures in consumer electronics logistics.

Altogether, the total GWP for transport from manufacturer to seller is approximately 1.61 kg CO_2eq per device. This value is used uniformly across all modelled scenarios to ensure comparability. However, it should be noted that actual emissions can vary considerably depending on company-specific logistics chains. These may involve different transport modes (e.g., sea instead of air), packaging formats, loading efficiencies, or distances. Where available, primary data from companies should therefore be integrated into the analysis to improve the accuracy of GWP estimates.

A summary of the transport assumptions and GWP calculations is provided in Table 8.

Table 8: Transport from Manufacturer to Seller (for all smartphone scenarios)

Category	Parameter	Unit	Assigned Value	GWP (kg CO_2eq)
Air	Destination	km	8860	1,6
	Payload-distance	kgkm	3202.71	
	GWP	kg CO_2eq/kgkm	0.0005	
Road	Destination	km	250	0,01
	Payload-distance	kgkm	90.37	
	GWP	kg CO_2eq/kgkm	0.000118	

Transport from Seller to First User

In addition to the transport from the manufacturer to the seller, the delivery of the product from the point of sale to the first user represents another relevant transport stage within the product's life cycle. This phase is modelled consistently across all smartphone scenarios to ensure comparability.

For the present analysis, it is assumed that the seller is located in Germany and delivers the device to a customer also based in Germany. The transport is carried out via road freight, with an average delivery distance of 450 km. This value is based on assumptions used in the Fairphone 2 LCA (Proske, Clemm, and Richter 2016), and reflects a realistic national delivery range that includes both urban and rural destinations.

As in the previous transport stage, the GWP is calculated using the payload distance approach, whereby the transported weight is multiplied by the delivery distance and an appropriate emission factor. With a total shipment weight of 0.361 kg per unit and an emission factor for road transport of 0.000118 kg CO_2eq/kgkm (VDE dialog 2023), this results in a payload distance of 162.45 kgkm and a corresponding GWP of approximately 0.019 kg CO_2eq per device.

This value is applied uniformly across all modelled scenarios. However, it is acknowledged that company-specific distribution practices – such as the use of third-party logistics providers, direct-to-consumer models, or differing warehouse locations – can lead to variations in transport distances and associated emissions. Where such information is available, it is recommended to use primary logistics data to refine the GWP calculations.

Transport within First Use

In contrast to conventional purchase models, rental scenarios may involve additional transport steps within the first use phase. Specifically, this includes the shipment of the device from the rental company to the end user, as well as its return at the end of the rental period. These additional logistics processes vary in extent depending on the number of renting cycles and the corresponding transport distances, with the resulting GWP adjusting accordingly.

The calculation follows the same methodological approach as in the previous transport stages, using payload distance and emission factors to determine the GWP. In the scenarios modelled here, it is assumed that each smartphone undergoes a single rental cycle before entering either the reuse or end-of-life phase.

Transport to Second Use

The transition of a device from its first to its second use phase entails an additional transport stage, which is included in all scenarios except the Baseline 1 model, where no second use occurs. This transport reflects the physical relocation of the device from the initial user to the next point of utilization and is modelled uniformly for comparability purposes.

For the present analysis, road transport over an average distance of 450 km is assumed, based on values from the Fairphone 2 LCA (Proske, Clemm, and Richter 2016). This distance is intended to reflect typical domestic transfers between users or between users and intermediaries (e.g., refurbishment centres). The GWP is calculated using the same methodology as in previous sections, applying the emission factor for road freight to the total transported weight and distance.

In rental scenarios, this transport may involve additional complexity. Here, the device is typically returned to the rental provider, and subsequently delivered to the next user. If refurbishment is outsourced to a third party, the device may also be transported to an external facility before it is redistributed. These additional logistics steps can increase the total transport distance and, accordingly, the associated GWP. However, for consistency and due to limited data availability, a standardized transport distance is applied across all scenarios in this model.

Where possible, company-specific logistics data should be used to refine these estimates and account for scenario-specific variations in reverse logistics and redistribution pathways.

4.3.2.1.3 Use Phase

GWP during the use phase of a smartphone is influenced by several factors, including the device's energy consumption, the power mix used during charging, and the duration of the use phase. This section outlines the assumptions and parameters used to calculate the GWP for the use phase.

First Use

The average battery capacity is assumed to be 12.41 Wh for all scenarios, based on the iPhone 13 as the reference device (Apple 2021). This assumption directly affects the energy required for charging the device. If different smartphones with larger or smaller batteries were used, the energy consumption and thus the GWP would change accordingly. The number of full charges per day is set at 0.8 for all scenarios, based on typical consumer behaviour (Sánchez, Baur, and Eguren 2024). This figure may vary depending on the actual usage patterns of end-users. For example, users with high phone usage may charge the device more frequently, leading to an increase in total energy consumption and, consequently, a higher GWP.

Additionally, an average battery loss of 0.1% per day is assumed, based on expert interviews. This means that the battery's capacity gradually degrades over time, leading to higher energy consumption to maintain the same performance level. In practice, the degradation rate may vary depending on factors such as the

device's age, charging practices, and battery quality. If the degradation is higher, the energy consumption (and therefore the GWP) would increase.

The GWP of the electricity mix in Germany for 2023 is set to 0.38 kg CO_2eq per kWh, based on data from Statista (Statista 2024). This factor is crucial in calculating the GWP of the energy consumed during the use phase. Regional differences in the electricity mix can significantly affect this value. For example, regions with a higher share of renewable energy would result in a lower GWP for the same energy consumption, whereas regions with a higher proportion of fossil fuels would yield a higher GWP. Summarized data can be found in Table 9.

The duration of the use phase varies between scenarios. In the baseline scenario, it is assumed that the device will be in use for approximately 43.2 months (i.e., 3.6 years), based on survey data (Circularity 2024). This assumption forms the basis for the GWP calculation presented in Table 9. However, this duration may differ in other scenarios, such as business or rental use, where the usage period may be shorter or longer depending on the specific circumstances of ownership or rental agreements.

In the rental scenario, the GWP calculation is generally the same as in other models, with one key distinction: the number of renting cycles is included in the calculation of the total active days of use. As devices are reused multiple times in rental scenarios, the total active use period is extended, potentially leading to a higher total GWP, depending on the number of cycles and their respective durations.

In summary, the GWP of the first use phase is directly influenced by the battery capacity, charging frequency, battery degradation rate, the power mix, and the duration of use. These assumptions are critical for calculating the energy consumption and associated emissions during the use phase. Variations in any of these factors, such as regional power mixes, user behavior, or battery performance, can lead to significant differences in the overall GWP calculation.

Table 9: Assumptions for First Use Smartphones

Category	Parameter	Unit	Assigned Value	GWP (kg CO_2eq)
Use Phase	Average Battery Capacity	Wh	12.41	5.45
	# of full charges per day	#	0.8	
	Average Loss	%	0.1	
	GWP Power Mix Germany	kg CO_2eq/Wh	0.00038	

Second Use

The second use phase of smartphones is assumed to be private across all scenarios. 3.6 years is assumed for all scenarios based on the user survey (Circularity 2024).

The GWP for second use is calculated in the same manner as for the first use phase, using the same assumptions outlined in the "First Use" section. These include factors such as average battery capacity, number of full charges per day, battery loss, GWP of the power mix, and the duration of use.

In the context of business models, different assumptions are made regarding the share of devices that are reused in the second use phase. For the Basis Market (private) scenario, it is assumed that 8% of smartphones are used a second time. This value is based on data from the B2C survey (Circularity 2024), which specifically focuses on private or non-commercial sources of second-hand devices. For the Basis Market (business) scenario, a 15% reuse rate is assumed. This estimate is derived from data indicating that 50% of devices reaching professionalized data deletion with potential resale go into further use, and 30% of companies pass on their devices, as per data from the survey and provided reports.

In the rental scenario (both private and business), it is assumed that 80 % of devices are reused in the second use phase. This figure is an educated estimate based on typical industry practices where rental devices are frequently resold or reused after the initial rental period. For the refurbishment scenario, a 70% reuse rate is assumed, which is also based on industry averages for devices undergoing refurbishment and subsequent resale. Thereby these numbers differ greatly between the different types and specialization of recommerce platforms and partners. Some are specialized on buying and reselling high value devices, only buying what can be more or less directly resold. Others focus more or low buying prices with a stronger strategy on repair within the refurbishment process. Other offer trade-ins for a whole range of devices with subsidies from external parameters like selling new devices. The share of devices going to reuse will vary

strongly between the different forms of recommerce. During this study, it became also clear that many devices do not stay within national or European boundaries for these recommerce processes. Also, the data on the device export is extremely scarce, this was included in the scenario. For rental, a share of 15% export with 75% reuse rate was assumed additionally to the direct reuse. For the resale scenario, 25% export with 75% reuse was assumed. As no information on the specific final destinations of these exports could be derived, the same assumptions on the exported second use as for the direct second use was applied.

These assumptions provide a foundational basis for estimating the GWP of the second use phase, but it is acknowledged that actual reuse rates can vary significantly depending on factors such as market demand, device condition, and the specific business model in question.

Repair/Refurbishment

In all scenarios that include more than one use phase (i.e., all except the linear baseline scenario), repair and refurbishment processes were considered. A generic greenhouse gas emission value of 2.42 kg CO_2eq per device was applied uniformly across these scenarios. This value is based on anonymized average company data collected from project partners and adapted to reflect the German electricity mix in 2023.

Due to limitations in the data, no distinction is made between repair (replacement of parts) and refurbishment within the overall refurbishment process. In practice, however, these processes differ significantly in scope and impact. A more precise modelling approach would require detailed data on failure rates, typical damage patterns, repair frequencies, and the number of components replaced or refurbished. Furthermore, since the definitions of "repair" and "refurbishment" vary across literature and industry practice, it is essential to clearly define these terms when developing a more granular analysis. As described in section 4.2.4.3 and 4.2.4.4, in this study, repair refers to hardware defects which limit the functionality of the device and often include the replacement of parts with spare parts. Refurbishment has the goal to return the device to a condition suitable for reuse and resale and includes data deletion, cleaning, cosmetic improvements, technical checks, and in some cases, upgrades or replacement of functional parts.

End of Life

For the End-of-Life (EoL) phase, uniform assumptions are applied across all scenarios. The GWP for this phase is based on the Life Cycle Assessment of the Fairphone 5 (Sánchez, Baur, and Eguren 2024), which provides a representative estimate for emissions related to the recycling of smartphones at the end of their use.

The EoL emissions include the recycling of relevant material fractions and are modelled consistently, independent of the preceding scenario. While real-life variations in recycling rates and infrastructure may exist, they are not accounted for in this study.

4.3.2.1.4 Additional assumptions in the scenarios

In addition to the core parameters defined within the individual life cycle stages, several scenario-specific key assumptions were made that influence multiple phases of the product's life cycle and differ across the scenarios. They are presented separately in the following section.

Table 10: Overview of additional assumptions (smartphone)

Scenario	Consumer group	1st use [months]	Share going to 2nd use [%]	2nd use [months]	Share being exported [%]	Share going to 2nd use in export [%]
Linear baseline	private	43.2	0%			
Baseline market	private	43.2	8%	43.2		
Baseline market	business	55.2	15%	43.2		
Reuse	private	26.4	70%	43.2	25%	75%
Reuse	business	43.2	50%	43.2	25%	75%

Scenario	Consumer group	1st use [months]	Share going to 2nd use [%]	2nd use [months]	Share being exported [%]	Share going to 2nd use in export [%]
Rental	private	18	80%	43.2	15%	75%
Rental	private	24	80%	43.2	15%	75%
Rental	private	36	80%	43.2	15%	75%

Days of Active Use

A key assumption in the modelling of scenarios is the number of active use days per year, meaning the number of days per year a device is actually in operation. This figure significantly affects energy consumption calculations and thus the total GHG impact across different use scenarios.

For consistency across all smartphone scenarios, a uniform assumption of 365 active usage days per year was applied, despite consumer survey data indicating slightly lower averages (e.g., 353 days for private users). This decision was made to maintain methodological alignment with energy consumption data provided by (Sánchez, Baur, and Eguren 2024), which are based on a full calendar year of daily charging. Using the empirically observed values from the survey would have required developing independent assumptions regarding daily energy consumption or charging frequency, thereby introducing additional uncertainties into the model.

This simplification ensures methodological consistency across scenarios while still reflecting real-world usage patterns in the background data. The slight deviation from observed values is considered acceptable given the alignment with publicly available lifecycle data (Sánchez, Baur, and Eguren 2024) and the importance of a consistent calculation base.

Duration of First Use Phase

The duration of the first use phase – that is, the period in which a smartphone is actively used by its initial user – is a critical factor influencing the overall environmental performance across scenarios. It affects not only the total energy consumed during use but also determines how many use cycles a device can go through within its technical lifespan.

In this study, the duration of the first use phase varies by scenario and user group. For the linear baseline scenario, which reflects a conventional linear use pattern, a duration of 3.6 years was assumed based on results from the consumer survey (Circularity 2024). This corresponds to 43.2 months, as shown in the scenario overview (Table 10).

This same value is applied for private consumers in the baseline market scenario, which accounts for the possibility of second use in a share of cases. For business users in the baseline market scenario, the first use phase is set at 4.6 years (55.2 months), based on data indicating longer usage cycles in institutional settings.

In the recommerce scenarios, the initial use phase reflects the time before a device is handed over for a second use. For private users, this is set at 2.2 years (26.4 months), reflecting relatively shorter ownership before resale. For business users, the first use is assumed to last 3.6 years (43.2 months), aligning with common replacement cycles in organizations.

The rental scenarios reflect intentionally shortened, cyclical use phases. Three rental variants are modeled for private users, with assumed first use durations of 18, 24, and 36 months respectively, capturing a range of contractual arrangements and user behaviors observed in the market. These values are derived from abstracted data shared by industry experts and reflect both short-term and extended rental offerings. In each case, one rental cycle is assumed for the first use phase, based on the data available to the study.

These values are summarized in Table 10 and serve as the basis for modelling emissions and reuse potential across all smartphone scenarios. These differentiated durations allow for realistic modelling of scenario-specific use patterns while ensuring comparability across business models.

Share going to Second Use

The share going to second use refers to the proportion of smartphones that are transferred to a second user or usage cycle after their initial period of use. This indicator is essential for modelling circularity impacts, as it directly influences the number of avoided new product purchases and thus the overall greenhouse gas emissions associated with smartphone lifecycles.

In this study, the values for second use shares vary across scenarios (see Table 10) and are derived from a combination of survey data, data provided by project partners, and expert-based estimations. For the private-use baseline market scenario, only 8% of devices are assumed to enter a second use phase. This value is derived from survey responses and reflects the small share of private users who pass on their devices through non-commercial channels.

In the business-use baseline scenario, a share of 15% was calculated based on internal partner data and survey results - assuming that 50% of collected devices are technically fit for further use and that 30% of companies actively pass on their devices.

Higher values are applied in scenarios with circular business models. For example, in rental and resale scenarios, shares of 50–80% are assumed, based on expert judgment and market expectations regarding the rate at which devices are prepared and reintroduced into the market after their first use phase.

Duration of Second Use Phase

In all scenarios considered in this study, the second use is assumed to be private, meaning that the device is not used as a business or company phone, but rather by an individual for personal purposes. The duration of this second use is set at 3.6 years (equivalent to 43.2 months) across all scenarios at product level (see Table 10), based on the same consumer survey data (Circularity 2024) used for the first use phase. This assumption represents a pragmatic simplification, as reliable data on actual second use durations is currently limited.

While this assumed duration offers a plausible basis for modeling, it carries inherent uncertainties. In reality, the length of second use may vary significantly depending on factors such as device condition, user behavior, and regional context. Therefore, the assumption primarily serves to enable comparability across scenarios and should not be interpreted as a precise estimate. Additional empirical research would be valuable to strengthen the data basis for future assessments.

Share being exported

The share being exported denotes the proportion of devices that are transferred to markets outside the country of first use following their initial or second use phase. Such exports typically occur when domestic demand is saturated or resale prices are more favourable abroad. Based on expert estimations, the model assumes export shares of 11% for rental and 19% for the recommerce scenarios, reflecting current patterns in the international trade of used electronic devices as described in more detail by Circularity 2025.

Share going to Second Use in Export

The share going to second use in export captures the proportion of exported devices that enter another active use phase in the destination country. To reflect the circular potential of global trade routes, the model assumes that 75% of exported devices are reused abroad. This estimate is based on expert judgment and aims to approximate the likelihood of continued use in secondary markets. While these secondary uses contribute to extending device lifetimes, limited transparency in global reverse supply chains introduces uncertainty regarding the exact use duration and end-of-life practices in export destinations.

4.3.2.2 Laptops

A comparable modelling approach was applied to laptops, covering all relevant life cycle stages and scenario dimensions. Since the methodology closely mirrors that used for smartphones, and to avoid repetition, the detailed assumptions and results are provided in section 7.5 in the annex.

4.3.2.3 Gaming Consoles

For the gaming consoles only scenarios with private users (linear baseline, market baseline, rental and resale) are considered.

4.3.2.3.1 Manufacturing

To assess the GWP associated with the manufacturing phase of a game console, a standardized set of assumptions was applied consistently across all scenarios to ensure comparability. The GWP calculation draws on literature values and project-specific estimations, covering the production of the game console itself – including one controller and cables – alongside associated packaging and printed documentation. An overview of parameters and data sources is provided in Table 11.

The manufacturing GWP of the console unit (including one controller and cables) is assumed to be 116 kg CO_2eq, based on (Poppe et al. 2024). This estimate aligns with typical values found in environmental assessments of modern game consoles, which tend to exhibit higher manufacturing emissions than smartphones due to their larger size, more energy-intensive components, and additional accessories.

Packaging emissions were estimated separately for the product box and transport box. For the product box, a weight of 0.508 kg was assumed, with cardboard as the primary material. Using an emission factor of 0.262 kg CO_2eq/kg for cardboard (based on Print.de (print.de 2023)), the associated GWP amounts to 0.13 kg CO_2eq. The transport box was assigned a weight of 0.66 kg, based on an educated assumption, with the same emission factor applied, resulting in 0.17 kg CO_2eq.

The documentation is modelled as a small printed leaflet weighing 0.0002 kg, based on data from ADEME et al. 2022. As in the smartphone model, the emission factor for paper is 0.0142 kg CO_2eq/kg (Umweltbundesamt 2023), which results in 3E-06 kg CO_2eq.

In total, the GWP for manufacturing all included components sums up to approximately 116.14 kg CO_2eq per game console unit.

While these assumptions provide a robust and consistent foundation for scenario comparison, several factors may influence actual manufacturing emissions:

- Device specifications, including internal hardware and performance capabilities, can drive significant differences in material and energy requirements.
- Material composition, particularly the ratio of metals (e.g., aluminium heatsinks, copper wiring) versus plastics or recycled components, heavily affects embodied emissions.
- Geographic and technological factors, such as the energy mix at manufacturing sites or regional differences in efficiency and sourcing, play a key role in determining emissions.
- Peripheral and packaging design, such as additional controllers, minimalistic versus elaborate packaging, and inclusion/exclusion of printed manuals, all contribute to the overall footprint.

As such, the values used in this model represent average, literature-based estimates and should be interpreted as consistent reference points rather than precise, device-specific measurements.

Table 11: Assumptions manufacturing gaming console

Category	Parameter	Unit	Assigned Value	GWP [kg CO2eq]
Game Console + 1 Controller + Cables	Manufacturing GWP	kg CO2eq	116.0	116.0
	Average Weight	kg	3	
Packaging	Product Box Weight	kg	0.508	0.31
	Product Box Material GWP	kg CO2eq/kg	0.262	
	Transport Box Weight	kg	0.660	
	Transport Box Material GWP	kg CO2eq/kg	0.262	
Extra	Documentation Weight	kg	0.0002	3E-06
	Documentation GWP	kg CO2eq/kg	0.0142	

4.3.2.3.2 Transport

As detailed data for specific transport routes is not available, we apply the same assumptions as used for smartphones (see 4.3.2.1.2). This approach is justified by the similarity of transport pathways for electronic products in general, covering transport from production to the point of sale, delivery to the first user, and potential transfer to a second use phase.

4.3.2.3.3 Use Phase

The use phase represents a major contributor to the overall GWP in the life cycle of gaming consoles. Unlike smartphones, whose energy consumption is relatively stable and low, gaming consoles show considerable variation depending on the mode of operation (e.g., active gaming, standby, or media playback) and user behaviour. To account for this, the GWP in this phase is calculated based on daily energy usage patterns across different operational modes and multiplied by the carbon intensity of the German electricity mix.

First Use Phase

The calculation distinguishes between days of active use and days of non-use. On active days, consoles operate in a variety of states, such as active gaming, menu navigation, standby, or media playback. On non-use days, devices are assumed to remain in an off state. Standby usage on non-use days was excluded due to minimal GWP contribution as shown in comparative analysis.

The average annual number of active use days may differ between the first use phase and the second use phase. The assumptions regarding usage days for each phase are presented in the subsequent section 4.3.2.3.4.

Energy consumption per usage day is determined using a weighted average across several gaming console models, based on typical daily usage time spent in each mode (Kilic 2020). Energy demand (in kWh) is then converted into GWP using the German electricity grid emission factor of 0.00038 kg CO_2eq/Wh (Statista 2024).

The calculated annual electricity demand for the average gaming console is approximately 36.90 kWh, corresponding to a total GWP of 67.91 kg CO_2eq, assuming a use period of 3,8 years in the linear baseline scenario.

Table 12: Use Phase – GWP from Electricity Consumption (First Use, Linear Baseline)

Category	Parameter	Unit	Assigned Value	GWP [kg CO_2eq]
Active Use Days	Average usage days per year	d/a	120.8	
	GWP per usage day	kg CO_2eq/day	0.14	
	Annual total GWP (active days)	kg CO_2eq	16.92	16.92
Non-Use Days	GWP per non-use day (standby)	kg CO_2eq/day	0.003	
	Non-use days per year	d/a	244.2	
	Annual total GWP (non-use days)	kg CO_2eq	0.78	0.78
Power Mix	German electricity grid GWP	kg CO_2eq/Wh	0.0004	
Total First Use				67.91

Second Use Phase

The GWP for the second use phase is calculated analogously to the first use phase. The number of active use days differs between the first and second use phases, as well as the scenarios, with the exact assumptions presented in 4.3.2.3.4..

Repair/Refurbishment

The methodological approach for estimating emissions from this phase follows the procedure applied in the smartphone chapter (see section 4.3.2.1.3), where primary data provided by industry partners involved in device refurbishment was used.

Across all scenarios, a uniform emission value of 8.21 kg CO_2eq is assumed for the repair and refurbishment phase. This value is derived from data originally collected for laptops. Due to the absence of more specific data for game consoles, the laptop-based estimate was adopted and adjusted using the German electricity mix (0.00038 kg CO_2eq per Wh).

End of Life

Based on (Sánchez, Baur, and Eguren 2024), emissions associated with the recycling process are estimated at 0.5 kg CO_2eq per device. Due to the lack of specific data for game consoles, this value – originally derived from assessments of smartphone recycling – was used as a proxy. It reflects average emissions from typical end-of-life treatment processes, including the separation and reprocessing of electronic components.

4.3.2.3.4 Additional assumptions in the scenarios

Like smartphones, there are also additional assumptions (see Table 13) for game consoles that influence multiple phases of the product's life cycle and differ across scenarios. These will be presented in the following section.

Table 13: Overview of additional assumptions (gaming console)

Scenario	Consumer group	1st use [months]	Share going to 2nd use [%]	2nd use [month]	Share going to export [%]	Share going to 2nd use in export [%]	Days of active use per year (1st use)	Days of active use per year (2nd use)
Linear baseline	private	45.6					121	
Baseline market	private	45.6	9%	44.4			121	121
Rental	private	18*1.5 rental cycles	80%	44.4	15%	75%	167	121
Reuse	private	26.4	70%	44.4	25%	75%	121	121

Duration of First Use Phase

The initial use duration significantly affects the environmental profile of each scenario. For the Baseline and Baseline Market scenarios, a duration of 45.6 months (approximately 3.8 years) was adopted based on empirical data (survey (Circularity 2024) and company-internal data from project partners), representing conventional ownership behaviour. In contrast, both rental and resale models are associated with shorter primary use phases. Specifically, the rental model assumes a first use phase of 27 months, which is divided into 1.5 rental cycles of 18 months each, while the resale model is associated with an even shorter duration.

Share going to second use

The proportion of devices entering a second use phase is a crucial factor in assessing reuse potential and circularity. In the Baseline Market scenario, only 9% of game consoles are assumed to be passed on, a figure derived from user survey responses indicating limited device handover in traditional ownership models. By contrast, Rental and Refurbishment scenarios assume that 80%, respective 70% of consoles undergo a

second use cycle, supported by expert judgment and existing market practices in circular systems where devices are actively collected, repaired, and redistributed. Additionally, 15% (rental) and 25% (resale) are assumed to be exported where 75% are going to be reused.

Duration of Second Use Phase

Across all relevant scenarios, the second use phase is standardized at 44.4 months (3.7 years). This assumption is based on average usage data from initial owners. While real-world variation in second-hand use durations is likely, this standardized value facilitates comparability across scenarios and was considered the most appropriate option in the absence of specific data for game consoles.

Days of Active Use

For most game console scenarios, 121 days of active use per year was applied (based on consumer survey), reflecting typical usage patterns observed in user survey data (Circularity 2024). An exception is made for the Rental scenario, where a higher usage frequency is assumed (167 days/year), representing more intensive utilization associated with short-term, access-based models.

4.3.2.4 Digital Cameras

Digital cameras were likewise modelled using the same scenario logic and life cycle framework as gaming consoles. Given the similarities in structure and data processing, all scenario-specific assumptions and outcomes for cameras are documented in Chapter 7.5.7 in the annex.

4.3.3 Company-specific adaption of the scenarios

Although the above methodology does not claim to comply with the WBCSD's Avoided Emissions Framework, it is consistent with some of its key principles. These include in particular the eligibility of the solution to mitigate climate damage, which in this case is the avoidance of new production through increased second-hand use through circular business models (WBCSD et al. 2023). To quantify avoided emissions in a systematic way, the guidance also proposes a 5-step approach which is as follows:

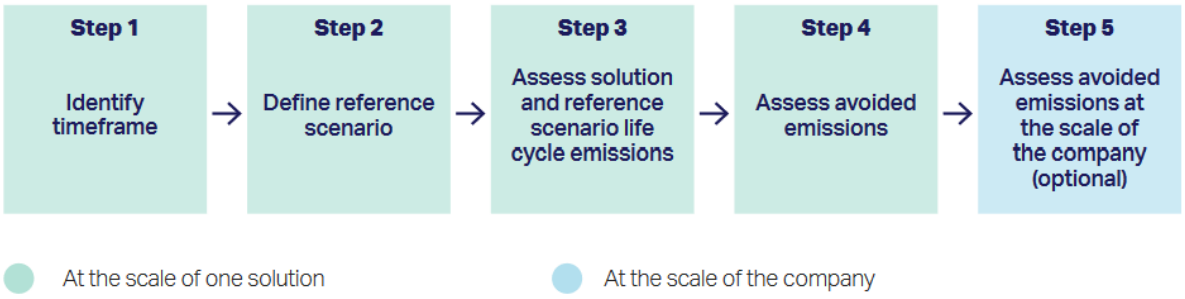

Figure 7: The 5-step approach to calculation avoided emissions (WBCSD et al. 2023, pg. 28)

Step 1: Identify the timeframe of the assessment.

A company identifies whether the solution's avoided emissions should be calculated on a forward-looking basis (all future life cycle avoided emissions are assessed in the year of sale), or on a year-on-year basis (avoided emissions are assessed every year from the year of sale, until the end of life of the solution). The timeframe should be consistent with the reporting timeframe of the solution's emissions in the company's GHG inventory assessment.

Step 2: Define the reference scenario.

The reference scenario depends largely on the context of sales, as it depends on the way solutions will be used and the alternative scenarios that would have been chosen instead. To ensure credibility and avoid overstating the impact of the solution in place, the reference scenario should reflect the situation without the given solution based on recognized and well-documented assumptions.

Step 3: Assess a solution and reference life cycle's emissions.

The company assesses life cycle emissions in a situation with the solution and in a reference scenario where the solution is not used.

Step 4: Assess a solution's avoided emissions.

This is established by calculating the difference in emissions of a reference activity with and without the solution being used, taking into consideration the solution's entire life cycle.

Step 5: Assess avoided emissions at the company scale.

Companies may assess their total avoided emissions by aggregating the avoided emissions of all solutions assessed following the four previous steps.

This can be applied to the described circular impact measurement by adjusting the circular business scenarios to the company-specific key parameters.

To derive accurate and meaningful greenhouse gas (GHG) emissions data within their own operations, companies should adapt the presented scenarios to their specific use cases and supply chains. While the scenarios in this study are based on general assumptions, literature sources, and publicly available data, confidential data provided by project partners has also been incorporated to enhance the robustness and applicability of the model.

To make comparisons with the company's actual activities and application of the circular business model, company-specific data needs to be integrated. Key parameters to consider include:

- Product (re)use
- Transport
- Own activities
- Handing over of devices/collaboration with partners

Device use and reuse is the first important factor to address: how long are devices actually used within renting models, how old are devices that are bought from private and business first users? The actual device usage duration may vary depending on internal policies, device types, user behaviour, and operational requirements. It is essential to document the number and length of usage cycles, including internal reuse or transfer of devices, and whether devices are retired or handed over to external partners after a single cycle.

The logistics and transport distances related to procurement, distribution, and return logistics must also be considered, including both external logistics emissions (Scope 3) and internal handling (Scope 1 and 2). This includes emissions from company-owned transport vehicles, warehousing processes, or refurbishment carried out in-house.

Further, companies should document emissions associated with their own activities. This includes data on the procurement of additional materials, such as spare parts, accessories, or packaging, which also contribute to the product's overall emissions. Energy for refurbishing and handling of devices needs to be assessed. This information can often be taken from existing corporate accounting.

Data and interview with companies over circular business models showed very clearly that in many cases circular business models are enabled by the cooperation of various partners along the supply chain. It is therefore important to document not only the own activities, but take into account how devices are handed over to partners. The actual condition of the devices when handed over to reuse or recycling partners should be assessed and – where possible – feedback from those partners should be obtained to verify whether devices were indeed reused or if they were recycled or discarded. This feedback is essential to determine the real-life second-use rate and to correctly allocate emissions in a circular system.

Strong collaboration with project partners, logistics providers, rental platforms, and refurbishers is key to improving data quality and enabling a more accurate, company-specific life cycle assessment.

A more detailed, practitioner-oriented description of the step-by-step application of the methodology – including references to the WBCSD step-by-step guide and concrete assumptions used in scenario modelling – can be found in the accompanying industry report (Circularity 2025).

4.4 Case study results for Circular Business Models

In the following, the results for the smartphone scenarios as described in section 4.2.4 are presented in section 4.4.1. The scenarios do not represent the operations of any specific service provider; rather, they are based on realistic average values and informed assumptions derived from survey results, expert interviews, and available market data.

The results are structured across three levels of analysis:

- **Product level**: The greenhouse gas emissions (GWP) are reported per year of (active) use and in relation to the device's total active lifetime following a specific device journey (without taking into account how often the specific journey talks place in the market).
- **Business model level**: The analysis takes into account that statistically not every device provided for reuse will end-up in a second use phase. For each case, the GWP per year of active use, the total active lifetime, and the respective shares of devices going into reuse or export are presented.
- **Market level**: Finally, results are aggregated to reflect different market developments, namely a purely linear model, the current market situation, and an optimistic circular scenario.

This structure allows a differentiated understanding of how device usage patterns and business models impact the environmental performance of smartphones. Additionally results for the business model level are presented for gaming consoles in section 4.4.2, which differ in their assessment regarding the allocation to the active days of use which are assumed to differ between device ownership and rental models.

The focus is therefore on the comparative analysis of different circular and linear usage scenarios. Accordingly, the following section provides a qualitative interpretation of the results across scenarios, while the exact numerical outcomes are documented in the appendix for reference.

It is important to note that the scenarios and results presented in this report may differ from those shown in the Circularity 2025 report. While both reports build on the same CBMI methodology, the assumptions, parameter values, and scenario definitions were partly adapted in order to explore additional business model variants, showcase specific tool functionalities (such as the export module), and address different analytical questions. These differences do not indicate inconsistencies, but rather reflect the methodological flexibility and broad applicability of the approach. The results in this report are therefore not directly comparable one-to-one with those in the industry report (Circularity 2025), but should be viewed as a complementary extension that deepens and broadens the analysis.

4.4.1 Smartphone case studies

Product level perspective

As previously introduced, "product level" analysis focuses on following a single device throughout its specific lifecycle. This approach isolates the environmental impacts of an individual product journey, allowing for a more detailed and precise assessment without averaging across broader device groups or user behaviours.

The relative results per year of use and the corresponding active service live of the device level assessment are presented in Figure 8. The absolute results can be found in Figure 9. Numeric results can be found in the annex in Table 15.

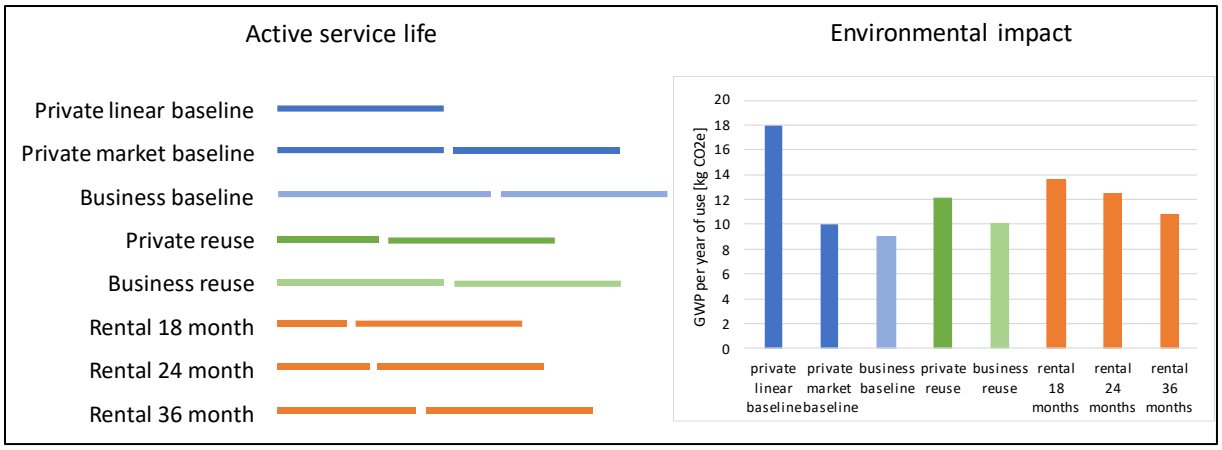

Figure 8: Active service life and corresponding environmental impact – product level perspective smartphones

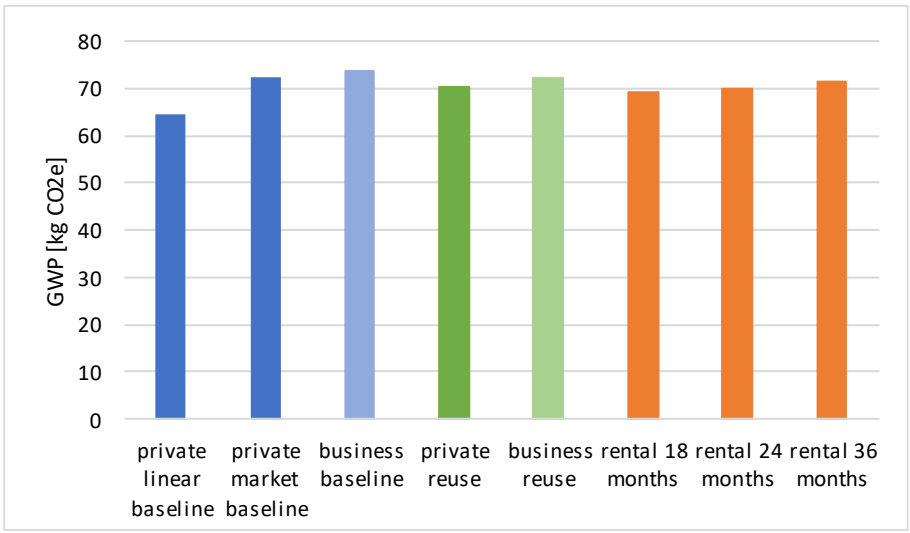

Figure 9: Absolute impact per scenario – product level perspective smartphones

It can be seen that the global warming potential per year of use on device level perspective is purely differentiated by overall active lifetime. As – based on the assumptions – the first use is much longer in peer-to-peer reuse (reflecting the average active lifetime on the market) than with renting and professionalized refurbishment, the direct re-use scenarios have the lowest impact per year of use. On the other hand, the purely linear use with only one use phase has the highest impact per year of use. Absolute impacts over the life cycle react in the opposite direction: with extension of the use phase the corresponding energy consumption increases.

While these findings are not directly attributable to a specific business model, they underscore the critical importance of maximizing the active use phase of individual devices in order to improve overall environmental performance. It also shows that the impact to enable reuse by repair and refurbishment is comparably small and pays off environmentally if the device is used longer as shown in Figure 10 (compare also Proske 2022).

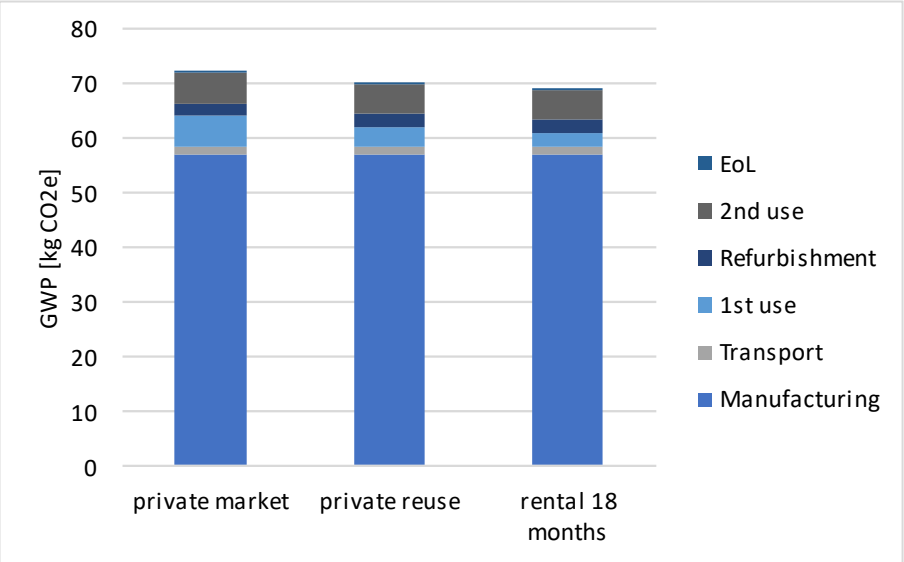

Figure 10: Environmental impact per life cycle phase exemplarily for three scenarios (product level perspective)

Business model perspective

As previously outlined, the business model level assesses the environmental performance of an entire circular business model scenario. In contrast to the product-level perspective, where the focus is on the full journey of a single device, the business model level considers the average active service life and environmental impacts of a group of devices operating under the same business model. This includes the aggregation of different product journeys – such as varying first and second use durations and different rates of devices entering second use – based on data-driven parameters derived from surveys and company data**.**

The relative results per year of use with the corresponding active service life are displayed in Figure 11. The absolute impacts of the full life cycle are shown in Figure 12.

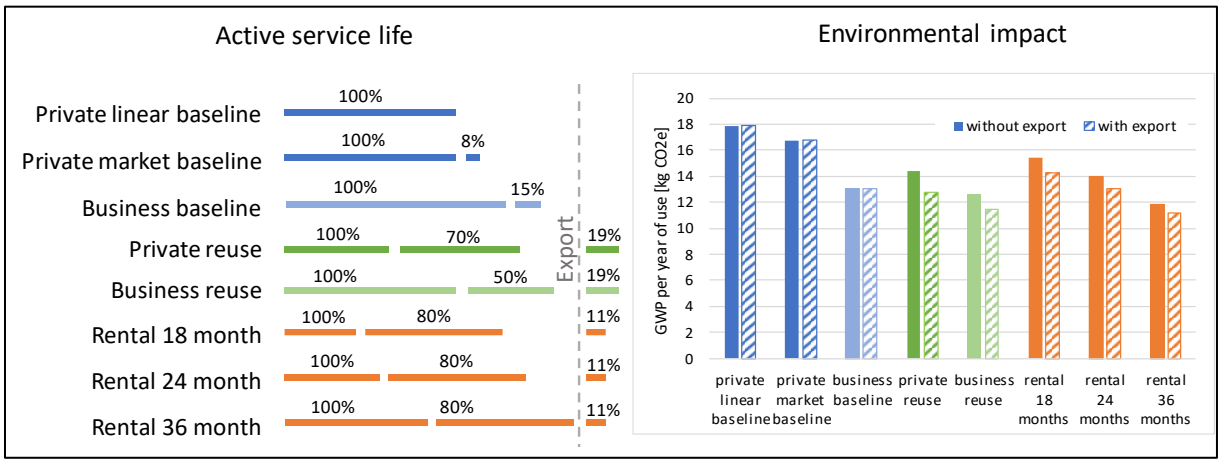

Figure 11: Active service life and corresponding environmental impact – business model perspective smartphones

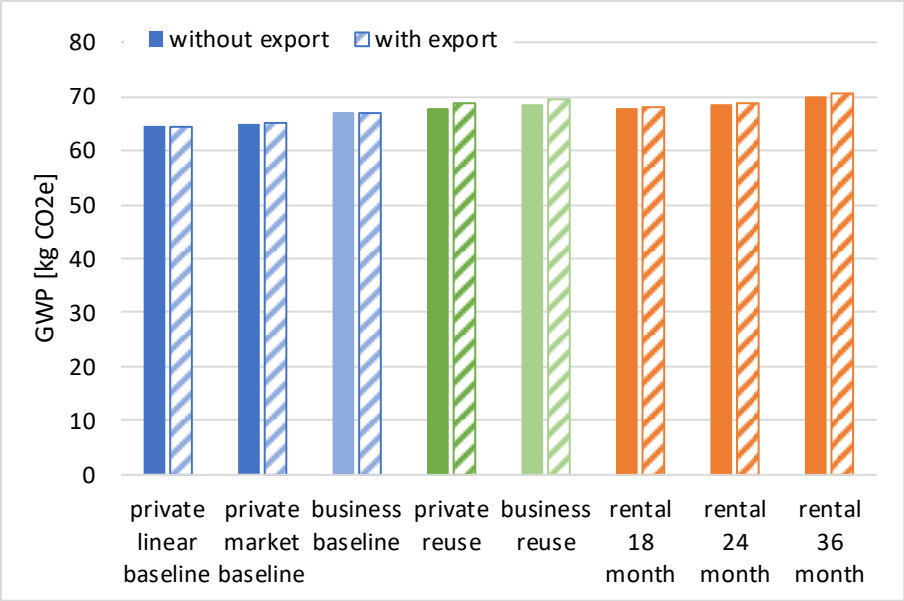

Figure 12: Absolute impact per scenario - business model perspective smartphones

The results clearly demonstrate that extending the active use phase of smartphones – through second-hand use, refurbishment, or rental business models – can substantially reduce the GWP per year of use. This holds true even though absolute emissions per device may increase due to additional refurbishment processes and transport-related emissions. The detailed numeric results are presented in the annex (see Table 14).

A key driver of environmental performance across scenarios is the share of devices that actually enter a second use phase. Currently, this share is only about 8% for peer-to-peer reuse, which results in a higher impact compared to circular business models with a much higher rate of devices achieving second use. The achieved active service life is more important than the additional effort required for repair and refurbishment. Only when the active service life is similar does efficient transport and refurbishment become a decisive factor for environmental efficiency between business models.

At the business model level, differences between linear and circular models become smaller. For instance, shorter initial use phases in rental models are compensated by a high rate of reuse, resulting in relatively low GWP per year of use overall. The analysis includes three private rental scenarios with typical contract durations of 18, 24, and 36 months, all assuming that 80% of devices enter a second-use phase after initial rental. As shown in Figure 11, longer rental durations lead to lower GWP per year of use, with the 36-month rental scenario achieving the lowest emissions among all assessed rental configurations.

Empirical data from project partners and interviews suggest significant variation in reuse rates between actors. Companies specializing in direct resale of high-quality devices tend to achieve higher reuse shares than those relying on trade-in or take-back programs targeting older or lower-specification devices. While achieving high reuse rates is environmentally advantageous at the business model level, it may also imply constraints at the market level, where the availability of suitable devices for second use is finite.

Finally, international device trade plays a critical role in enabling second use when domestic demand or device quality is insufficient. As discussed in section 4.3, data on exported devices and their actual use in destination markets remain scarce. In the model, similar reuse conditions in export markets are assumed. Under this assumption, exports provide an additional opportunity to extend device lifespans instead of being recycled and reduce GWP per year of use, particularly for devices that would otherwise not be reused locally.

Market level perspective

This approach enables a structured comparison between the current market situation – which already incorporates a certain share of second-hand and rental models – and a hypothetical scenario characterized by purely linear consumption patterns. By modelling different market compositions and uptake rates of circular business models, it becomes possible to assess how shifts in consumer behaviour and business practices may alter the overall environmental impact of the sector over time. The analysis focuses on systematically quantifying differences in key metrics such as total active use time and associated global warming potential (GWP) across alternative market structures. Additionally, the market level perspective is

applied – with the highest uncertainty regarding the specific numbers. The idea of this perspective is to show how the currently already existing availability of reuse has a positive effect on a given market compared to a fictional purely linear market and how the potential uptake of these CBMs could offer further improvement.

Three potential markets with parallel existence of linear use, second-hand devices and rental devices are analysed: a purely linear market, a market which reflects the current market and optimistic circular market with a strong uptake of second-hand devices and renting services. The purely linear market assumes that in a (fictious) given market 100 Mio. smartphones are used for 3.6 years and then recycled without further second hand (Figure 13). This is not reflecting the current situation even without specialized CBM providers. A current market based on the user survey is displayed in Figure 14.

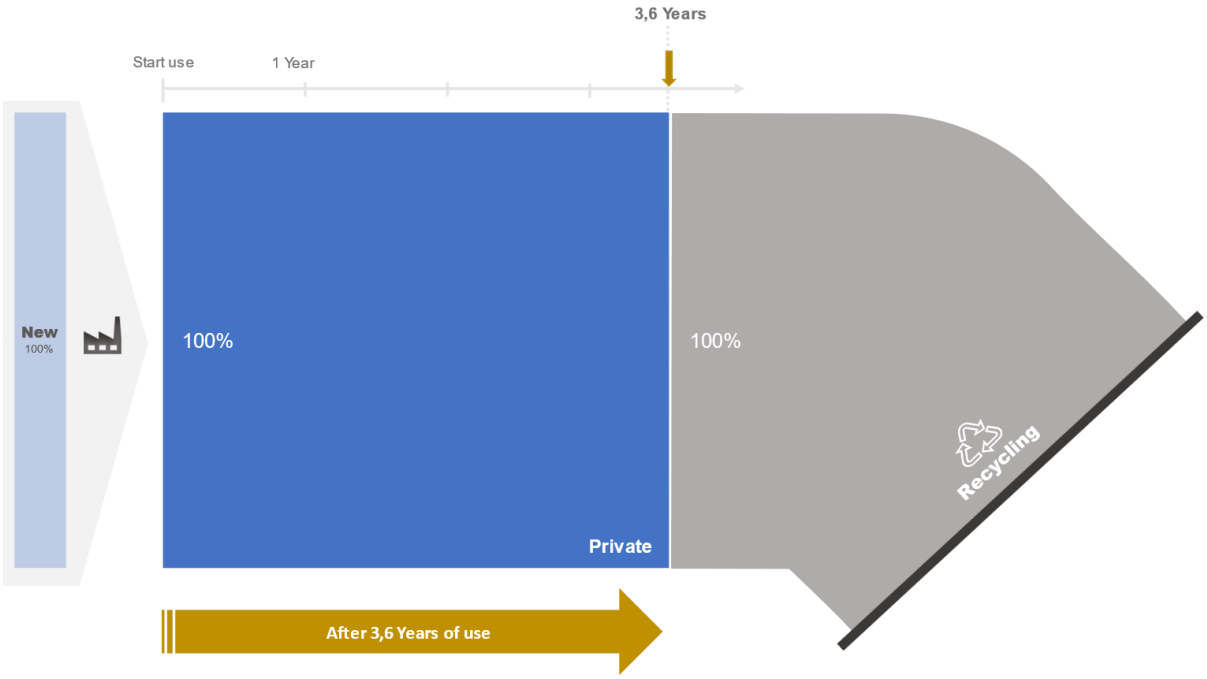

Figure 13: Market level perspective - linear market

In the current market scenario, about 80% of the devices are used only by one average user. 19% of the devices are owned and then handed-over to re-use – and based on the survey, thereby used for a shorter period – and about 1% of devices are already used within rental services before being handed over to reuse. On the other hand, the input side of the devices shows that only about 14% of devices are actually second-hand devices – displaying the earlier discussed mismatch between provided to second hand and used second hand. This reflects the availability of international input and output of devices from and to other markets as well devices being discarded by refurbishers as not being suitable for reuse.

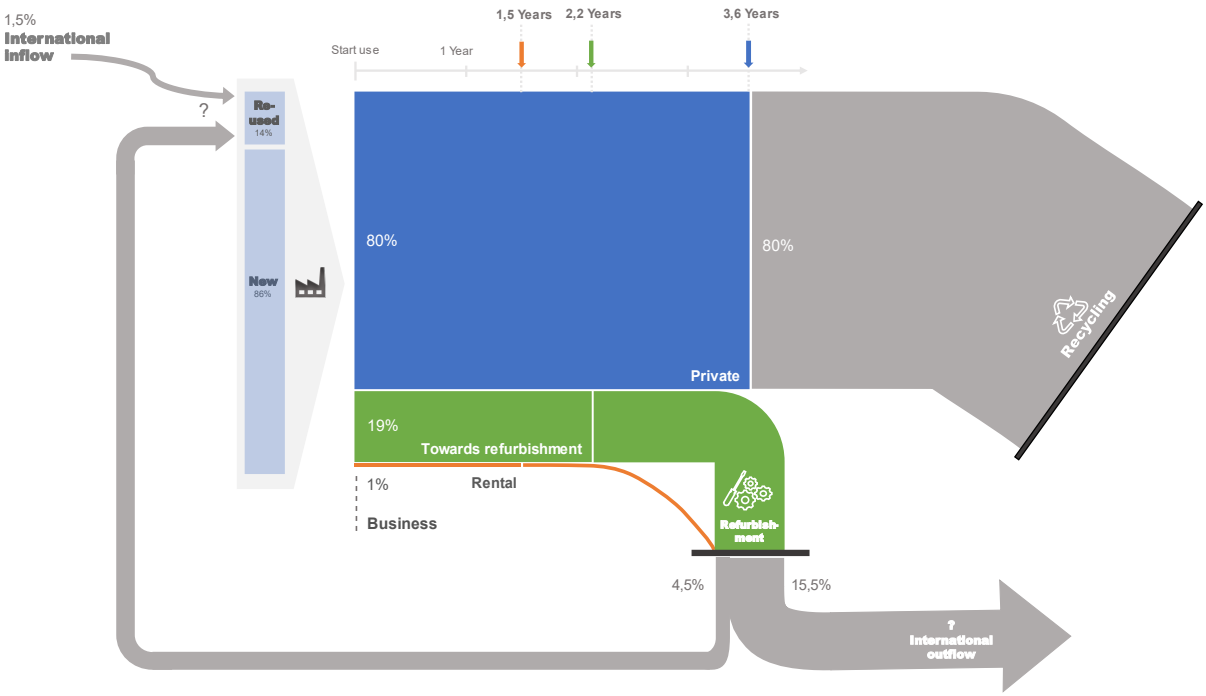

Figure 14: Market level perspective – current market

The last Figure 15 shows an optimistic circular market where 30% of devices used are second hand and 15% of devices are rented rather than owned.

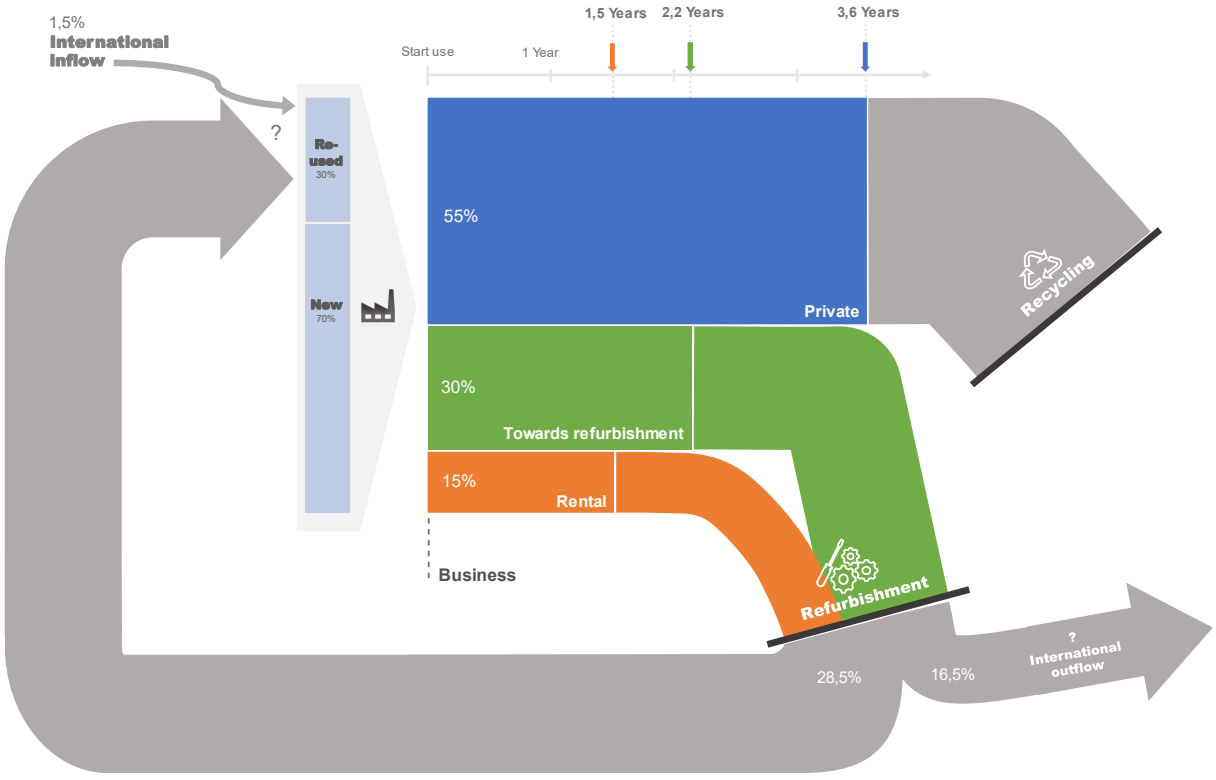

Figure 15: Market level perspective – optimistic circular market

Figure 16 shows the results of these three different markets per year of use, where the impact is reduced through longer of use of the devices, showing savings compared to these shown with the business model perspective. Critical for the market level, is the mismatch between provided for reuse and actually reused. If there is a big mismatch due to devices being discarded, this could lead to an actual acceleration of the devices as users replace their devices early subsidized by resale and trade-in. If the mismatch is rather caused

by device export, the given market could still be negatively affected and benefits would happen in a different market (showing the need to assess a whole device with the circular impact assessment). Depending on the export market, the devices could increase the overall consumption level there, leading to rebound effects.

High reuse rates should generally be pursued, but attention must also be paid to minimizing mismatches between the number of devices made available for reuse and those actually reused – both within and across markets.

While international second-hand flows can have positive environmental effects by extending product lifetimes, they may also create challenges, such as market distortions or unaccounted environmental burdens in receiving regions. A balanced reuse strategy should therefore aim to maximize actual device reuse while considering systemic and geographical consequences.

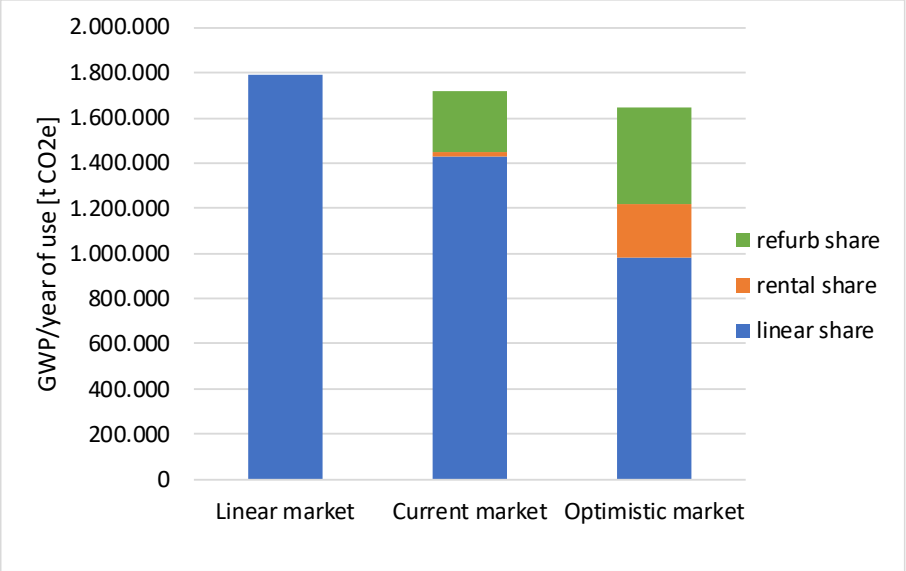

Figure 16: Results on market level - smartphones

4.4.2 Gaming consoles case studies

Gaming consoles are, as described, an infrequently-used product. Thereby, CBMs offer the possibility to connect users for periods with high activity and reducing devices not only by extending the (calendar) active servicer life but also by increasing the use intensity (similar to sharing activities). Here we applied the higher use intensity for the renting periods by differing the number of active days per year. In the following, the results on business level perspective are presented per service life (similar to smartphones) in Figure 17 and per active day of use in Figure 18.

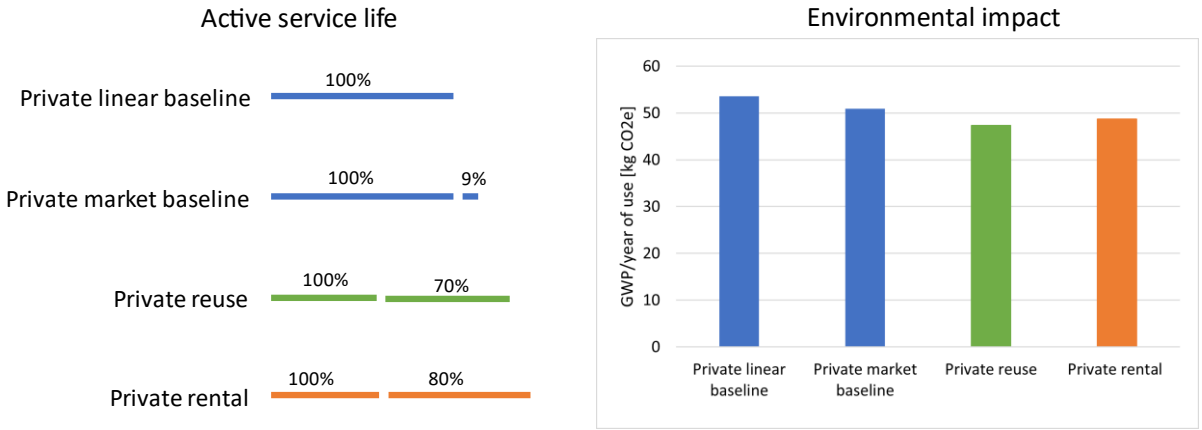

Figure 17: Business model perspective gaming consoles - service life

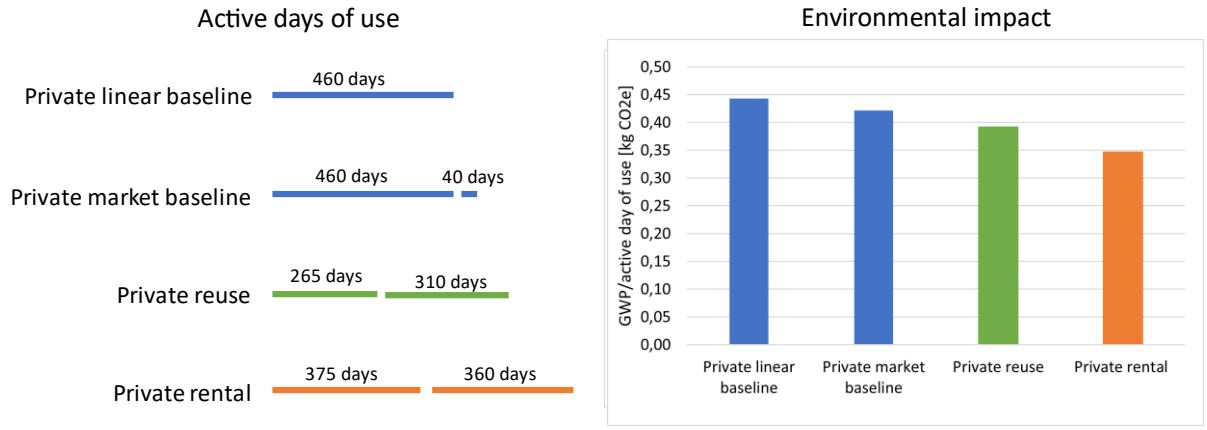

Figure 18: Business model perspective gaming consoles – active days of use

The comparison shows that similar to smartphones, lifetime extension is beneficial. However, when total service life is quite similar like between the assumed rental and resale scenario, the number of transport and refurbishment processes do play a small role regarding the impact per year of use. However, if a CBM enables a reducing the number of devices by increasing the use intensity of existing devices – as modelled through the active days of use – there is further potential to reduce the environmental impact beyond just increasing the calendar service life.

4.5 Model review and sensitivity

In the following section, a model review and sensitivity analysis are presented to evaluate the robustness of the findings and identify key factors influencing environmental performance. The analysis focuses on the GWP per year of use across different (circular) business models and usage scenarios.

Variation of rental cycles

An interesting aspect of the rental model is the impact of rental duration versus rental frequency. While all scenarios aim for extended total use phases (typically through reuse after initial rental), the length of each rental period significantly influences environmental performance as analysed in the scenarios above. However, extending the service life can be achieved by extending the duration per renting cycle or by increasing the number of rental cycles (see Figure 19).

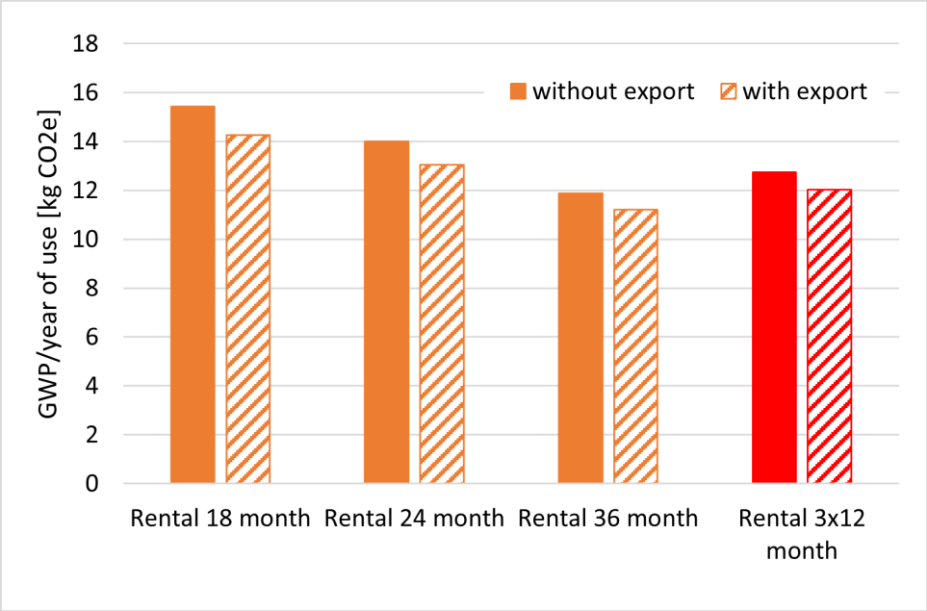

Figure 19: Sensitivity analysis – variation of rental cycles with similar service life

The results show that the 36-month rental option achieves the lowest GWP per year of use due to fewer device handovers and thus lower cumulative emissions from transportation, refurbishment, packaging, and repairs. However, 3x12 month rental scenario still outperforms the scenarios with 24- and 12-month rental period.

This suggests that extending the service life is beneficial even when more handling effort is needed. Nevertheless, longer individual use phases are more environmentally efficient, as they minimize refurbishment-related overheads per year of device use.

Variation of service life

A further way to investigate the influence of usage duration assumptions on the overall model is to analyze different device lifetimes in the first use – either by increasing total use time in a single-user context or by prolonging the first-use phase before reuse (see Figure 20).

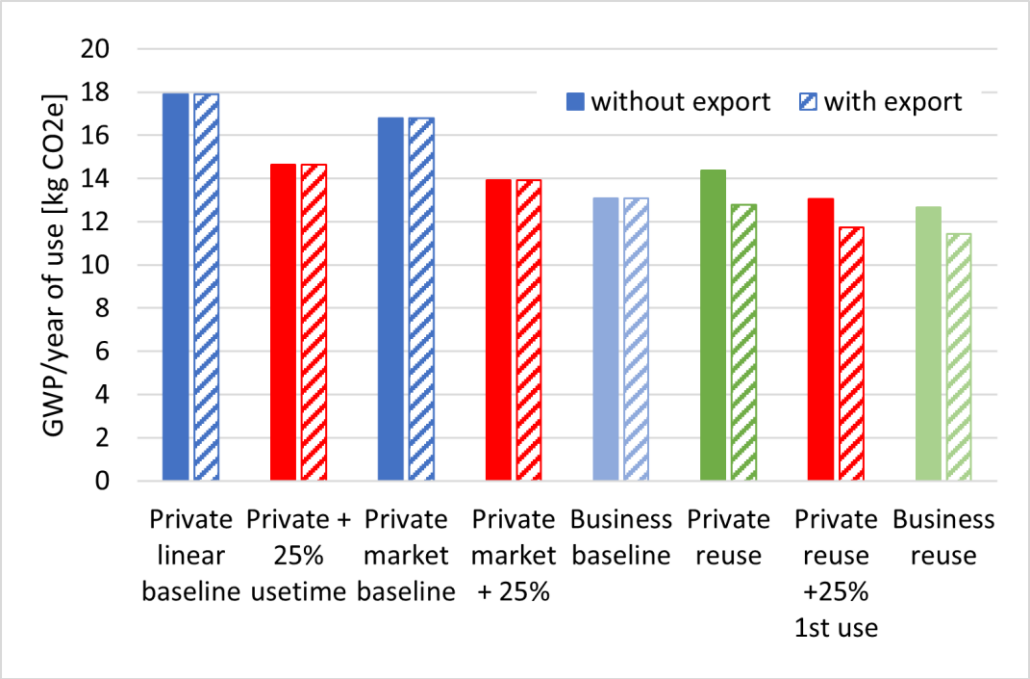

Figure 20: Sensitivity analysis – extension of service life

In the first case, the average use time is extended by 25% in a private ownership model, without involving reuse. This results in a significant improvement: the GWP per year of use drops from 17.9 to 14.6 kg CO_2eq/a. This scenario avoids emissions from refurbishment and logistics entirely, demonstrating that longer private use alone can yield substantial environmental benefits.

In the second case, the focus is on increasing the duration of first use before a device enters the reuse cycle. When first use is extended by 25% (from 26.4 to 33 month in the, private reuse scenario), GWP per year of use decreases from 14.4 to 13.0 kg CO_2eq/a (without export) and from 12.8 to 11.7 kg CO_2eq/a (with export). This shows how the difference between average use and shorter first use before reuse influence postponing reuse can enhance the overall efficiency of circular models, since fewer refurbishments and transports are required over the device's full life.

Variation of refurbishment effort

Furthermore, it is also interesting to assess the role of refurbishment in the overall environmental impact of reuse models. In this context, two sensitivity scenarios were examined: one assuming a doubling of refurbishment efforts and the other assuming a halving of those efforts. The aim was to evaluate how changes in refurbishment intensity affect emissions related to device reconditioning and associated logistics. The analysis revealed that, while the refurbishment effort is relevant, it has only a marginal impact on the

overall GWP per year of use. Despite significant variations in refurbishment efforts, the duration of active use remains the dominant factor influencing environmental outcomes (see Figure 21).

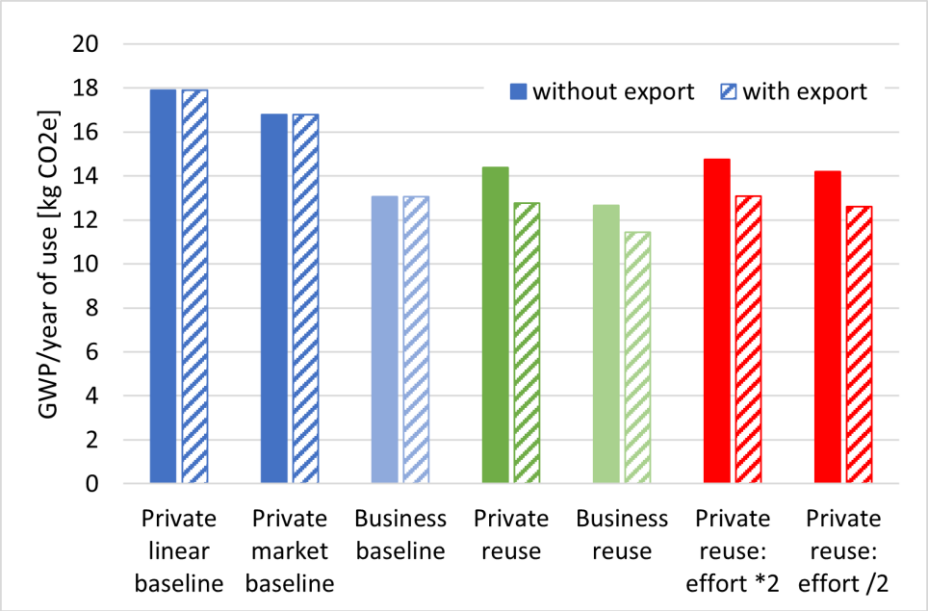

Figure 21: Sensitivity analysis – variation of refurbishment effort

An important factor influencing the environmental impact of refurbishment is the condition of the device. Devices in poor condition require more extensive repair efforts, leading to higher resource use and emissions, whereas devices in good condition may require less refurbishment and thus incur lower emissions. However, within the scope of this model, it is assumed that the differences in refurbishment effort, regardless of device condition, do not drastically alter the overall environmental outcome.

The findings of this analysis emphasize that the duration of active use is the most significant factor in determining the environmental impact of a device. The extended use of a device leads to a substantial reduction in GWP, far outweighing the effects of variations in refurbishment intensity. Even when the refurbishment effort is doubled, the GWP per year of use remains lower than that of alternative models, such as linear use or private market scenarios, where devices are used without reuse or refurbishment.

Therefore, the results suggest that optimizing reuse rates and extending the active use duration of devices has a considerably stronger leverage on reducing GWP than further marginal improvements in refurbishment efficiency. While minimizing the environmental impacts of refurbishment is still valuable, especially in high-volume reuse systems, it is clear that the greatest environmental benefits are achieved through maximizing reuse rates and extending the lifespan of devices.

5 Discussion and Conclusion

This report provides insights into how electronic devices are used and reused in Germany. In many cases, reuse is facilitated by circular business models (CBMs) and professional providers that offer services such as refurbishment, resale, or rental. The environmental impact of these CBMs was assessed through multiple scenarios and compared to predominantly linear usage patterns currently observed in Germany.

The scenarios show that CBMs can lead to clear environmental benefits by extending the active service life of devices. However, these benefits are smaller than those reported in some other studies and methodological frameworks (see section 2.1).

This is not due to poorer performance of CBMs themselves, but rather the result of a more comprehensive and conservative assessment approach that considers the full product lifetime – including both first and second use—in all scenarios. In contrast, many previous studies apply a cut-off logic, treating first and second use independently, which can lead to an overestimation of circular benefits.

By accounting for real-world dynamics – such as the fact that not all devices offered for reuse are actually reused, or that first use durations vary significantly depending on the business model—this report offers a more nuanced and realistic estimate of circularity impacts.

5.1 Comparison of Scenarios and Key Findings

As described in section 4.4, circular business models in our analysis at the market and business model level demonstrated environmental benefits compared to the linear baseline or the current market with a professionalized second-hand sector. Key parameters influencing the benefit were the total active use time – comprising the first use phase (or total rental time in the case of the renting scenarios) – as well as the share of devices achieving a second life and the duration of their second use. Device handling and additional transports influenced the absolute results to some extent, but had a comparatively lower effect.

On the product level, the main driver of environmental performance is the total active lifetime assumed, which limits the visibility of differences between business models unless changes in usage patterns are explicitly modelled.

The circular impact measurement presented here shows that the relative environmental benefit of circular business models is around 20% - a value lower than the 40–70% range reported in earlier studies (typically 40–70%, see section 2.1). This discrepancy is primarily due to more comprehensive and conservative assumptions regarding total active use time. In particular, the modelling approach considers that not all devices handed over to second-hand channels are actually reused and that the first use duration of devices entering recommerce is often shorter than the market average. These effects, also discussed in earlier work (e.g.,Wieser and Birkner-Tröger 2015.), are frequently not captured in studies that apply a cut-off approach – i.e., that allocate environmental impacts only to the first or second use phase in isolation.

By applying an integrated modelling approach that accounts for real-world inefficiencies and uncertainties, a more conservative but realistic estimate of circular benefits is provided.

Based on the scenarios, the advantages of rental models are closely tied to their ability to enable structured second use pathways rather than to a direct extension of device use within the rental period itself. In other words, the environmental benefit depends significantly on how many devices are successfully passed on after the rental cycle ends. The proportion of devices transitioning into secondary use emerged as a critical factor. This proportion varied significantly across different actors and was often not directly traceable by the companies handing over the devices. This variability does not indicate a lack of commitment but rather reflects the structural complexity of reuse ecosystems, in which ownership and usage responsibilities are distributed across multiple stakeholders. As a result, the activities and outcomes of business models that appear similar on the surface can diverge significantly in practice, complicating the development of generalized scenarios.

The findings do not suggest that reuse or rental models are inherently less sustainable than long-term device use by a single owner. Instead, the results underscore that system-level efficiency depends on actual usage behavior across all life cycle stages. While continued use of a device by the original owner over its full technical lifetime would yield the lowest environmental impact in theory, this idealized case is not reflective of mainstream consumer behavior. Survey data (Circularity 2024) indicate that a substantial share of users replace devices before reaching end-of-life – highlighting the importance of resale and rental models as

instruments to extend actual usage durations. The core challenge lies not in the business model itself, but in ensuring that secondary use is both realized and effective.

Rebound effects – such as earlier replacement due to trade-in options or increased consumption driven by perceived device availability – are only indirectly accounted for in this assessment, namely through shorter first-use durations. However, survey data (Circularity 2024) suggest that such effects may occur and should be considered in future analyses. In particular, if early replacement is incentivized by resale and trade-in schemes, this may reduce the environmental benefits associated with second use. The net impact depends not only on the replacement decision but also on whether the device is subsequently reused and how long it remains in use.

Finally, it is important to acknowledge that real-world data remains scarce in many areas, which poses challenges for further analysis and a comprehensive understanding of the dynamics at play in this field. This lack of data is especially relevant for two factors of the scenarios:

- Share of devices being reused
- Duration of second use

The share of devices being reused strongly influences the resulting total active lifetime of a range of devices treated by a company. This number not only differs strongly between actors, but also includes for many refurbishers a further B2B sale of the devices In such cases, it is often unclear what happens to the devices: how many are actually reused, where they end up — including whether they are exported and used abroad – and for how long. These uncertainties make it difficult to define generalized scenarios.

The second difficult number in the differentiation of the scenarios is the duration of second-hand use. Where the user survey (Circularity 2024) allowed to differentiate first use between different user groups and ways of purchasing, this was not possible for professionalized second-hand purchasing as the users did not know the initial source of their devices. The scenarios assumed the same time for second use for the different scenarios although the different age of the devices may influence the duration of the second use.

5.2 Implications for Businesses and Policymakers

Up to now, there is not much evidence that rental models lead to longer service lives within the rental periods than conventional device purchase, and the number of rental cycles per device remains rather low. With this in mind, the environmental benefit is often attributed not primarily to extended use during the rental itself, but rather to more structured and direct handovers to refurbishment and reuse, resulting in higher shares of devices entering a second use phase.

From the perspective of assessing potential avoided impacts, the question of comparison is essential. As pointed out in section 2, it may be that the business model of device rental appeals only to a specific user segment, whose behaviour differs significantly from the average in the reference or baseline scenarios. Realistic comparative scenarios must therefore not only reflect average consumer patterns but also account for these differences in user profiles and consumption behaviour. Rentals may carry the risk of increased rebound effects by facilitating quicker replacement cycles; however, they may also simply formalize patterns that already exist in linear consumption models for certain user groups.

At the same time, the combination of rental and subsequent resale (recommerce) can link different user types through the lifecycle of a single device, thereby increasing the likelihood of extended total use. From a service provider perspective, the goal should be to design these systems as efficiently as possible—minimizing idle time between users and enabling multiple rental cycles where feasible, in order to prevent devices (especially rapidly evolving models like smartphones) from becoming technologically outdated before their potential is fully utilized.

What becomes apparent from the background analyses conducted within this project is that circular business models typically require collaboration among several specialized actors. They are seldom implemented entirely within a single organization and depend on the smooth handover of responsibilities across the value chain.

Moreover, most current CBMs are built on the reality that many consumers replace their devices before reaching the end of their technical life span. As described by Hollander and Bakker (2016), these models can be understood as "gap-exploiters" – they aim to close the gap between early replacement and full use potential, rather than encouraging end-of-life usage.

This does not negate their positive contribution, but it highlights the importance of consumer behaviour: ideally, devices would be used until the end of their technical lifespan, including repair when necessary. In practice, this remains the exception rather than the norm. CBMs such as rental and resale offer important mitigation strategies, but they cannot fully substitute for long-term use and repair by the original user. Communicating this distinction clearly is crucial – to avoid overestimating the impact of CBMs while still recognizing their value within current patterns of device use.

Devices suitable for refurbishment are typically those that have been used moderately and are still in good technical condition. Renting companies primarily serve the demand for new devices and rarely continue to offer older device generations for extended rental periods. Instead, such devices are commonly transferred to refurbishers and subsequently enter the second-hand market. However, based on information provided by participating project partners, some rental companies are currently working to expand their offerings to include second-hand rentals. This includes both the rental of externally sourced used devices and the re-rental of previously leased equipment, particularly within B2B contexts. These developments aim to address different price segments and contribute to prolonged device lifecycles.

Although the circular impact measurement had to rely on assumptions in many cases, the analysis showed that total active use time is by far the most influential factor for environmental performance, whereas device handling, refurbishment, and transport have comparatively smaller impacts. This suggests that additional effort to refurbish and remarket even older devices could be environmentally worthwhile, even if economic incentives may be limited.

The analysis further highlights the strong dependency of circular benefits on the actual reuse rate, which remains difficult to quantify due to limited transparency along the value chain. This underlines the need for improved collaboration and consistent communication of key performance indicators (KPIs) between actors. Only with such transparency can the specific characteristics and environmental performance of a company's business model be accurately evaluated.

Equally important is a complete assessment of the device's entire life cycle—not only the second use phase enabled by a circular model but also any potentially shortened first use compared to conventional ownership. This is essential to allow a realistic and credible communication of circular business model benefits.

From a scientific perspective, the methodological approach developed and applied in this study represents an important step forward in the evaluation of circular economy strategies. In contrast to many previous studies, which often rely on idealized assumptions or separate the first and second use phases artificially, this methodology integrates real-world usage behaviour and allows for nuanced, data-informed modelling of device lifetimes. By focusing on the use phase and actual user behaviour rather than just end-of-life scenarios, the method contributes to a more robust and policy-relevant understanding of circular business models in practice. This strengthens the evidence base for companies, researchers, and policymakers seeking to assess the realistic environmental potentials – and limitations – of circular strategies in consumer electronics.

5.3 Limitations and Further Research

Many limitations of the current analysis and parameters of the scenarios were already discussed. Data is scarce on user- as well as company side.

Duration of active use in first and second life were based on different user surveys, which always include the risk of users not remembering their actions correctly, do not stick to their own plans and are known to give socially-accepted answers (Di Polizzi Sorrentino, Woelbert, and Sala 2016). Although they are currently the best available information on that part, they might still differ from actual behaviour. Additionally, surveys always have a limited set of questions to be manageable, so they do not cover all relevant and interesting information and different surveys might not always interlink ideally.

Additionally, historical data is scarce and a survey is always a snapshot. Whereas there is indication that service lifetime of smartphones is actually extending (Frick, Jaeger-Erben, and Hipp 2020), also the CBM are still rather new on the market. Especially in the rental market, services are provided by very young and growing companies. As these companies evolve, also the way they are offering and consumers are using their services evolves. Timeline data suggest that currently the renting times of the devices becomes longer, but not all of these could be finally assessed (as e.g. planned contract duration increased from 2022 to

2024, but how well this is achieved cannot finally be assessed in 2025). This report should therefore be seen as an analysis of the levers rather than a conclusive assessment of the business models.

From the parameters on the company side, the project showed that there is a limited number of companies active with strong variations of their specific business model and range of covered activities. This leads to the fact that it is difficult to build analysis for a "circular business model" but rather for a specific characteristic. Additionally, data which rely on the handover of devices between partners are not known by all relevant actors (e.g. which share of the devices from renting are actually sold into reuse by the refurbishers).

More data of the actual application of the analysed business model on market level is needed. This should also address more information on international device flows and how they affect reuse quotas, transport emissions and potential material losses from recycling.

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7 Appendices

7.1 Overview – Results business model level perspective

Table 14: Results for smartphones, laptops, cameras, gaming consoles – business model level perspective

Product group	Scenario	GWP per year of use w/o export [kg CO_2eq]	GWP per year of use with export [kg CO_2eq]	GWP absolute w/o export [kg CO_2eq]	GWP absolute with export [kg CO_2eq]
Smartphone	Private baseline	17.90	17.90	64.44	64.44
	Private market baseline	16.78	16.78	65.05	65.05
	Business baseline	13.06	13.06	67.14	67.14
	Business reuse	12.66	11.43	68.39	69.42
	Private reuse	14.37	12.77	67.85	68.88
	Rental 18 months	15.43	14.25	67.58	68.20
	Rental 24 months	14.00	13.05	68.33	68.95
	Rental 36 months	11.88	11.21	69.85	70.47
Laptop	Private baseline	82.02	82.02	360.87	360.87
	Private market baseline	78.61	78.61	369.41	369.41
	Business baseline	86.58	86.58	545.64	545.64
	Private reuse	66.39	62.13	420.22	438.70
	Business reuse	78.55	74.28	528.03	542.82
	Private rental	83.88	79.46	450.46	461.55
	Business rental	79.04	75.44	483.73	494.82
Camera	Private baseline	10.94	10.94	36.09	36.09
	Private market baseline	10.34	10.34	36.28	36.28
	Business baseline	4.40	4.40	37.42	37.42
	Private reuse	9.59	8.47	38.63	38.74
	Private rental	7.05	6.70	42.80	42.86
Game console	Private baseline	53.56	53.56	203.53	203.53
	Private market baseline	50.91	50.91	210.10	210.10
	Private reuse	47.36	43.67	226.86	239.47
	Private rental	48.70	46.44	253.74	261.30

7.2 Overview – Results product level perspective

Table 15: Results for smartphones. laptops. cameras. gaming consoles - product level perspective

Product group	Scenario	GWP per year of use [kg CO_2eq]	GWP absolute [kg CO_2eq]
Smartphone	Private baseline	17.90	64.44
	Private market baseline	10.05	72.34
	Business baseline	9.01	73.85
	Private reuse	12.11	70.22
	Business reuse	10.05	72.34
	Private rental 18 months	13.56	69.15
	Private rental 24 months	12.48	69.91
	Private rental 36 months	10.82	71.43
Laptop	Private baseline	82.02	360.87
	Private market baseline	56.89	472.22
	Business baseline	67.53	641.54
	Private reuse	60.63	454.71
	Business reuse	77.46	641.54

Product group	Scenario	GWP per year of use [kg CO_2eq]	GWP absolute [kg CO_2eq]
	Private rental	76.87	472.73
	Business rental	73.33	506.00
Camera	Private baseline	10.94	36.09
	Private market baseline	6.26	38.80
	Business baseline	3.28	37.42
	Private reuse	8.11	39.76
	Private rental	6.54	43.49
Gaming console	Private baseline	53.56	203.53
	Private market baseline	37.05	277.88
	Private reuse	42.23	249.17
	Private rental	45.14	268.61

7.3 Smartphones

Table 16: GWP for private/business baseline and reuse scenarios (smartphone, business model level)

Steps \ Scenario	Private baseline	Private market baseline	Business baseline	Business reuse	Private reuse
Manufacturing	56.98	56.98	56.98	56.98	56.98
Transport from Manufacturer to Seller	1.61	1.61	1.61	1.61	1.61
Transport from Seller to First User	0.02	0.02	0.02	0.02	0.02
First Use	5.45	5.45	6.97	5.45	3.33
Transport to Second Use		0.00	0.00	0.01	0.01
Refurbishment/Repair		0.19	0.36	1.21	1.70
Second Use		0.42	0.82	2.73	3.82
EoL	0.38	0.38	0.38	0.38	0.38
Total GWP per smartphone	64.44	65.05	67.14	68.39	67.85
GWP per day in use	0.049	0.046	0.036	0.035	0.039

Table 17: GWP for rental scenarios 18/24/36 months (smartphone, business model level)

Scenario / Steps	Rental 18 months	Rental 24 months	Rental 36 months
Manufacturing	56.98	56.98	56.98
Transport from Manufacturer to Seller	1.61	1.61	1.61
Transport from Seller to First User	0.02	0.02	0.02
First Use	2.27	3.03	4.54
Transport to Second Use	0.02	0.02	0.02
(within Rental)	(0.00)	(0.00)	(0.00)
Refurbishment/Repair	1.94	1.94	1.94
(within Rental)	(0.00)	(0.00)	(0.00)
Second Use	4.36	4.36	4.36
EoL	0.38	0.38	0.38
Total GWP per smartphone	67.58	68.33	69.85
GWP per day in use	0.042	0.038	0.033

7.4 Gaming Consoles

Table 18: GWP for rental scenario (gaming console, business model level)

Steps	GWP Total	GWP per Day in Use
Manufacturing	116.31	0.061
Transport from Manufacturer to Seller	18.59	0.010
Transport from Seller to First User	0.22	0.000
First Use	54.42	0.029
EoL	0.50	0.000
Refurbishment within Rental	4.1063	0.002
Transport within Rental	0.11	0.000
Transport to Second Use	0.18	0.000
Refurbishment/Repair	6.57	0.003
Second Use	52.74	0.028
Total per Game Console	**253.74**	0.133

Table 19: Overview GWP for all scenarios (gaming console, business model level)

Steps \ Scenario	Private baseline	Private market baseline	Rental	Private reuse
Manufacturing	116.31	116.31	116.31	116.31
Transport from Manufacturer to Seller	18.59	18.59	18.59	18.59
Transport from Seller to First User	0,22	0.22	0.22	0.22
First Use	67.91	67.91	54.42	39.20
Transport to Second Use (within rental)		0.02	0.18 (0.11)	0.15
Refurbishment/Repair (within rental)		0.73	6.57 (4.11)	5.75
Second Use		5.83	52.74	46.14
EoL	0.50	0.50	0.50	0.50
Total GWP per Gaming Console	203.53	210.10	253.74	226.86
GWP per day in use	0.147	0.139	0.133	0.130

7.5 Laptops

All assumptions and values for linear baseline scenario.

7.5.1 Manufacturing

Table 20: Manufacturing GWP for private market baseline scenario (laptop)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)
Laptop	Manufacturing GWP	kg CO_2eq	225	Poppe et al. 2024	225.0
	Average Weight	kg	2	Poppe et al. 2024	
Charger	Manufacturing GWP	kg CO_2eq/kg	1.94	Sánchez, Proske, and Baur 2022	1.94
	Average Weight	kg	0.35	Amazon.de 2025b	
Packaging	Product Box Weight	kg	0.740	Ercan et al.	0.37
	Product Box Material GWP	kg CO_2eq/kg	0.262	print.de 2023	
	Transport Box Weight	kg	0.66	Ercan et al.	
	Transport Box Material GWP	kg CO_2eq/kg	0.262	print.de 2023	

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)
Extra	Documentation Weight	kg	0.00048	Ercan et al.	0.0000068
	Documentation GWP	kg CO_2eq/kg	0.0142	Umweltbundesamt 2023	
Total weight [kg]			**3.75**	**GWP Manufacturing**	**227.31**

7.5.2 Transport

Table 21: Transport from Manufacturer to Seller GWP for private market baseline scenario (laptop)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)
Air	Destination	km	8860	Proske, Clemm, and Richter 2016	16.61
	Payload-distance	kgkm	33229		
	GWP	kg CO_2eq/kgkm	0.0005	Rodrigue 2024	
Road	Destination	km	250	Proske, Clemm, and Richter 2016	0.11
	Payload-distance	kgkm	937.62		
	GWP	kg CO_2eq/kgkm	0.000118	VDE dialog 2023	
GWP Transport to Seller					**16.73**

Table 22: Transport from seller to first user GWP for private market baseline scenario (laptop)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)
Road	Destination	km	450	Proske, Clemm, and Richter 2016	0.20
	Payload-distance	kgkm	1687.72		
	GWP	kg CO_2eq/kgkm	0.00	VDE dialog 2023	
GWP Transport to First Use					**0.20**

Table 23: Transport to second use GWP for private market baseline scenario (laptop)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO2eq)
Road	Destination	km	450	Proske, Clemm, and Richter 2016	0.20
	Payload-distance	kgkm	1687.72		
	GWP	kg CO_2eq/kgkm	0.00	VDE dialog 2023	
GWP Transport to Second Use					**0.20**

7.5.3 Use Phase

Table 24: First use GWP for private market baseline scenario (laptop)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO2eq)
Use Phase	Energy consumption per year	kWh/a	66	Internal data	110.35
	Energy consumption per day of use (private)**	kWh/day	0.1903		
	GWP per active use day (private)	kg CO_2eq	0.07231		
	GWP Power Mix Germany	kg CO_2eq/Wh	0.00038	Statista 2024	
GWP First use					**110.35**

Table 25: Second use GWP for private market baseline scenario (laptop)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)
Use Phase	Energy consumption per year	kWh/a	66	Internal data	97.81
	Energy consumption per day of use (private)	kWh/day	0.1903		
	GWP per active use day (private)**	kg CO_2eq	0.0723		
	GWP Power Mix Germany	kg CO_2eq/Wh	0.00038	Statista 2024	
GWP Second Use					**97.81**

**: To calculate the energy consumption for both private and business usage days. various operational modes were considered ("Off". "Standby". "Idle". "Low Active". "Mid Active". "High Active"). For this purpose. the power consumption and corresponding time values (based on internal data) were multiplied to determine the total daily energy consumption.

For private use. a daily usage period of 6 hours was assumed: 1 hour each in the "Idle" and "High Active" modes. and 4 hours in the "Mid Active" mode. For business use. an 8-hour working day with a 1-hour break was assumed. This includes 1 hour in "Idle" mode. 2 hours in "High Active" mode. and 6 hours in "Mid Active" mode. The remaining hours of the day were categorized as "Off." The power consumption was defined as 0.3 W for "Idle". 10 W for "Mid Active". 150 W for "High Active". and 0 W for "Off". Based on these assumptions. the resulting daily energy consumption is 0.19 kWh/day for private use and 0.36 kWh/day for business use.

7.5.4 EoL after first use

Table 26: EoL after first use for private market baseline scenario (laptop)

Category	Parameter	Source	GWP (kg CO_2eq)
End of Life	Recycling	Sánchez, Baur, and Eguren 2024	0.5
GWP EoL			**0.5**

7.5.5 Total Days of Use

Table 27: Total days of use for private market baseline scenario (laptop)

First Use		Sources
Average Use Period (years)	4.4	Circularity 2024
Average Use Period (months)	52.8	
Average Use Period (days)	1606	
Days of Active Use	1606	
% of devices in Second Use	8%	Results from Circularity 2024 reduced "private"/non-commercial sources of second hand devices
Second use		
Average Use Period (years)	3.9	Circularity 2024
Average Use Period (months)	46.8	
Average Use Period (days)	1423.5	
Days of Active Use	1423.5	
Total		
Total Days of Use		1715.2
Total Days of Active Use		1715.2

7.5.6 Results

GWP in kg CO_2eq.

Table 28: Total GWP for private market baseline scenario (laptop, business model level)

Steps	GWP Total	GWP per day in use
Manufacturing	227.31	0.133
Transport from Manufacturer to Seller	16.73	0.010
Transport from Seller to First User	0.20	0.000
First Use	116.14	0.068
EoL after First Use	0.50	0.000
Transport to Second Use	0.02	0.000
Refurbishment/Repair	0.63	0.000
Second Use	7.90	0.005
EoL after second use (total EoL in first number)		0.000
Total GWP per laptop	**369.41**	**0.215**

7.5.7 Overview for all scenarios (laptop, business model level)

Table 29: Overview GWP for all scenarios (laptop, business model level)

Scenario / Steps	Private baseline	Private market baseline	Business baseline	Business reuse	Private reuse	Private rental	Business rental
Manufacturing	227.31	227.31	227.31	227.31	227.31	227.31	227.31
Transport from Manufacturer to Seller	16.73	16.73	16.73	16.73	16.73	16.73	16.73
Transport from Seller to First User	0.20	0.20	0.20	0.20	0.20	0.20	0.20
First Use	116.14	116.14	279.85	219.01	95.02	112.44	149.92

Steps \ Scenario	Private baseline	Private market baseline	Business baseline	Business reuse	Private reuse	Private rental	Business rental
Transport to Second Use (within rental)		0.02	0.06	0.06	0.20	0.16 (0.10)	0.16 (0.00)
Refurbishment/ Repair (within rental)		0.63	2.46	2.46	8.21	6.57 (4.11)	6.57 (0.00)
Second Use		7.90	18.53	61.76	72.06	82.35	82.35
EoL	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Total GWP per smartphone	360.87	369.41	545.64	528.03	420.22	450.46	483.73
GWP per day in use	0.225	0.215	0.237	0.215	0.182	0.230	0.217

7.6 Cameras

All assumptions and values for private reuse scenario.

7.6.1 Manufacturing

Table 30: Manufacturing GWP for private reuse scenario (camera)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)	GWP (kg CO_2eq)
Camera	Manufacturing GWP	kg CO_2eq		WERTGARANTIE 2022/2023	28	28.0
	Average Weight	kg	0.9	Poppe et al. 2024		
Charger	Manufacturing GWP	kg CO_2eq/kg		Sánchez, Proske, and Baur 2022	1.94	1.94
Packaging	Box Weight	kg	0.279	Amazon.de 2025a	0.07	0.07
	Box Material** GWP	kg CO_2eq/kg	0.262	print.de 2023		
Extra	Documentation Weight	Kg	0.00048	Ercan et al.		7E-06
	Documentation GWP	kg CO_2eq/kg	0.0142	Umweltbundesamt 2023		
Total weight [kg]			**1.18**	**GWP Manufacturing**		**30.01**

*: Product documentation

**: 95% Carton/Wood Fibre (iPhone 13)

7.6.2 Transport

Table 31: Transport from Manufacturer to Seller GWP for private reuse scenario (camera)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)
Air	Destination	km	8860	Proske, Clemm, and Richter 2016	5.2274
	Payload-distance	kgkm	10455		
	GWP	kg CO_2eq/kgkm	0.0005	Rodrigue 2024	
	Payload-distance	kgkm	0.00		
	GWP	kg CO_2eq/kgkm	0.000008	Rodrigue 2024	
Road	Destination	km	250	Proske, Clemm, and Richter 2016	0.03
	Payload-distance	kgkm	90.37		
	GWP	kg CO_2eq/kgkm	0.000118	VDE dialog 2023	
GWP Transport to Manufacturer					**5.26**

Table 32: Transport from seller to first user GWP for private reuse scenario (camera)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq)
Road	Destination	km	450	Proske, Clemm, and Richter 2016	0.06
	Payload-distance	kgkm	531		
	GWP	kg CO_2eq/kgkm	0.000118	VDE dialog 2023	
GWP Transport to Seller					**0.06**

7.6.3 Use Phase

Table 33: First use GWP for private reuse scenario (camera)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq) per year
Use Phase	Energy per load cycle*	Wh	4.14	Akku.net 2023	0.15
	Load cycles per year	#	43.94		
	Average Loss	%	0.1		
	Shutter Releases per Use	#	200		
	Shutter Releases per Year (Active Use)	#	8788.65		
	Max. Shutter Releases per Battery Load	#	200	Akku.net 2023	
	GWP Power Mix Germany	kg CO2eq/Wh	0.00038	Statista 2024	
GWP First Use					**0.15**

*: (Battery voltage * battery capacity) for a compact digital camera (Li-Ion)

Table 34: Second use GWP for private reuse scenario (camera)

Category	Parameter	Unit	Assigned Value	Source	GWP (kg CO_2eq) per year
Use Phase	Energy per load cycle	Wh	4.14	Akku.net 2023	0.22
	Load cycles per year	#	43.94		
	Average Loss	%	0.1		
	Shutter Releases per Use	#	200		
	Shutter Releases per Year (Active Use)	#	8788.65		
	Max. Shutter Releases per Battery Load	#	200	Akku.net 2023	
	GWP Power Mix Germany	kg CO2eq/Wh	0.00038	Statista 2024	
GWP Second Use					**0.15**

7.6.4 EoL after first use

Table 35: EoL after first use GWP for private reuse scenario (camera

Category	Parameter	Source	GWP (kg CO_2eq)
End of Life	Recycling	Sánchez, Proske, and Baur 2022	0.5
GWP EoL			**0.50***

7.6.5 Total Days of Use

Table 36: Total days of use for private reuse scenario (camera

First Use		Sources
Average Use Period (years)	2	Circularity 2024
Average Use Period (months)	24	
Average Use Period (days)	730	
Days of Active Use	87.886	
% of devices in Second Use	70%	Results from Circularity 2024 reduced to "private"/non-commercial sources of second-hand devices
Second use		
Average Use Period (years)	2.9	Circularity 2024
Average Use Period (months)	34.8	
Average Use Period (days)	1058.5	
Days of Active Use	127.44	
Total		
Total Days of Use		1471
Total Days of Active Use		177.09

7.6.6 Results

Table 37: Total GWP for private reuse scenario (camera, business model level perspective)

Steps	GWP Total	GWP per day in use
Manufacturing	30.01	0.02
Transport from Manufacturer to Seller	5.26	0.004
Transport from Seller to First User	0.06	0.00004
First Use	0.15	0.0001
EoL after First Use	0.50	0.0003
Transport to Second Use	0.06	0.00004
Refurbishment/Repair	0.63	0.0016
Second Use	7.90	0.0001
EoL after second use (total EoL in first number)		
Total GWP per laptop	**38.63**	**0.026**

7.6.7 Overview for all scenarios (Camera, business model level)

Table 38: Overview GWP for all scenarios (Camera, business model level)

Steps \ Scenario	Private baseline	Private market baseline	Business baseline	Private reuse	Private rental
Manufacturing	30.01	30.01	30.01	30.01	30.01
Transport from Manufacturer to Seller	5.26	5.26	5.26	5.26	5.26
Transport from Seller to First User	0.06	0.06	0.06	0.06	0.06
First Use	0.25	0.25	1.58	0.15	0.46
Transport to Second Use		0.00	0.00	0.06	0.06
(within rental)					(0.09)
Refurbishment/ Repair		0.17	0.00	2.42	2.42
(within rental)					(3.63)
Second Use		0.02	0.00	0.15	0.28
EoL	0.50	0.50	0.50	0.50	0.50
Total GWP per smartphone	36.09	36.28	37.42	38.63	450.46
GWP per day in use	0.030	0.028	0.012	0.026	0.230