Circular Bonding COOCK

M5: Circularity potential of circular bonding technologies

Ive Vanderreydt, Stefanie De Smet, Emma Pals, Alexej Parchomenko, Wim Van Opstal

Circular bonding: a ‘best of both worlds’ solution

Adhesives

- ✓ Thin
- ✓ Lightweight
- ✓ Transparent
- ✓ No drilling required

- × Designed to stick (permanently)
- × Limited disassembly potential for bonded elements

Circular bonding

Fasteners

- ✓ Easy disassembly

- × Heavy solution
- × More spacious
- × Requires permanent holes in substrate

Circularity opportunities of reversible bonding are situated in the inner (reuse, repair…) & outer (recycle) circles

	Circular Strategies		Potential of circular bonding		Example
1	**Refuse** **Rethink** **Reduce** **Redesign**	– Making the product redundant by abandoning its function or providing the same function with a radically different product – Make product use more intensive (e.g. by sharing the product). – Increasing efficiency in the production or use of the product by consuming fewer natural resources and materials. – Redesign the product to eliminate waste, while keeping the functionality intact	**Medium**	– The decision to shift from traditional adhesives to reversible adhesives impact the product design phase but not (necessarily) in a circular way given it is a mere replacement of an existing input – Strategies further down the ladder are enabled by the use of reversible bonding (indirectly) igniting rethink, reduce and redesign initiatives	Reversible bonding facilitates repair and refurbish strategies which enables (higher-value) product-service systems (Rethink)
2	**Reuse** **Repair** **Refurbish**	– Reuse a product multiple times for the same purpose by the original owner or by new users – Repair the product or offer repairs to prolong the product's useful life – Refurbish the product to bring it back into the cycle through cosmetic alteration	**High**	– Reversible bonding = easier disassembly which facilitates / enables the repair and refurbishment of components that would previously be (irreversibly) damaged by 'tearing' components apart	Motor of a coffee machine was previously glued in such that it could not be replaced with reversible bonding, the motor can be taken out without damaging the rest of the machine Carpet flooring can easily be (partly) refurbished if reversible bonds are used
3	**Remanufacture** **Repurpose**	– Disassemble components of a product that has become waste and rebuild the same product – Disassemble components of a product that has become waste and use in another product	**High**	– Reversible bonding = easier disassembly which facilitates / enables the takeout and reuse of (still) operational components in a similar or different product (remanufacture, repurposing)	If a device with a touchscreen breaks down, reversible bonding allows for the expensive and fragile screen to be taken out and remanufactured in new equipment
4	**Recycle**	– Process materials to recover/ transform (high quality) products from waste streams into basic material	**High**	– Easier disassembly allows for more advanced recycling methods and/or higher value recycling outputs	Smartphone recycling can be split in battery recycling (containing most rare metals) and case recycling (mostly plastics)
5	**Recover**	– Burn materials to generate energy	**Low**	– Limited value-add of having used a reversible adhesive when materials are burned to generate energy	n.a.

The circularity potential of circular (de)bonding technologies is evaluated from three different perspectives

Functionality perspective
The preservation of functionality of the adhesive, substrates and particles when debonding

Environmental perspective
The effect on environmental impact due to different material use (compared to traditional bonding) and energy demand of the debonding process

Economic perspective
The price of (applying) debondable adhesives, investment costs required for debonding technologies and costs of post debonding cleaning

Potential of circular bonding

- Circular bonding (& debonding) allows the re-use of certain components and/or materials, thereby prolonging its lifespan. This could entail benefits on functionality, environmental and economic impacts.
- However, it is possible that the alternative bonding process and/or the debonding process could outweigh this benefit
- In the current analysis, the scope is limited to debonding technologies (and to potential impacts downstream of the respective product value chain it is applied in)
- Different debonding methods are possible. The analysis of these technologies from CE perspective is presented in the following table
  - Functionality: the preservation of functionality of the adhesive, substrates and particles
  - Environmental: the effect on environmental impact due to different material use (compared to traditional bonding) and energy demand of the debonding process
  - Economic: the price of debondable adhesives, investment costs needed for debonding technologies and costs of post debonding cleaning

Analysis of debonding technologies at lab scale from CE perspective

Disclaimer: Table provides only an overview - in specific cases deviations might occur

HIGH | MEDIUM | LOW | ✦ Application dependent | ✧ Adhesive dependent

Scaling only applies within the same column

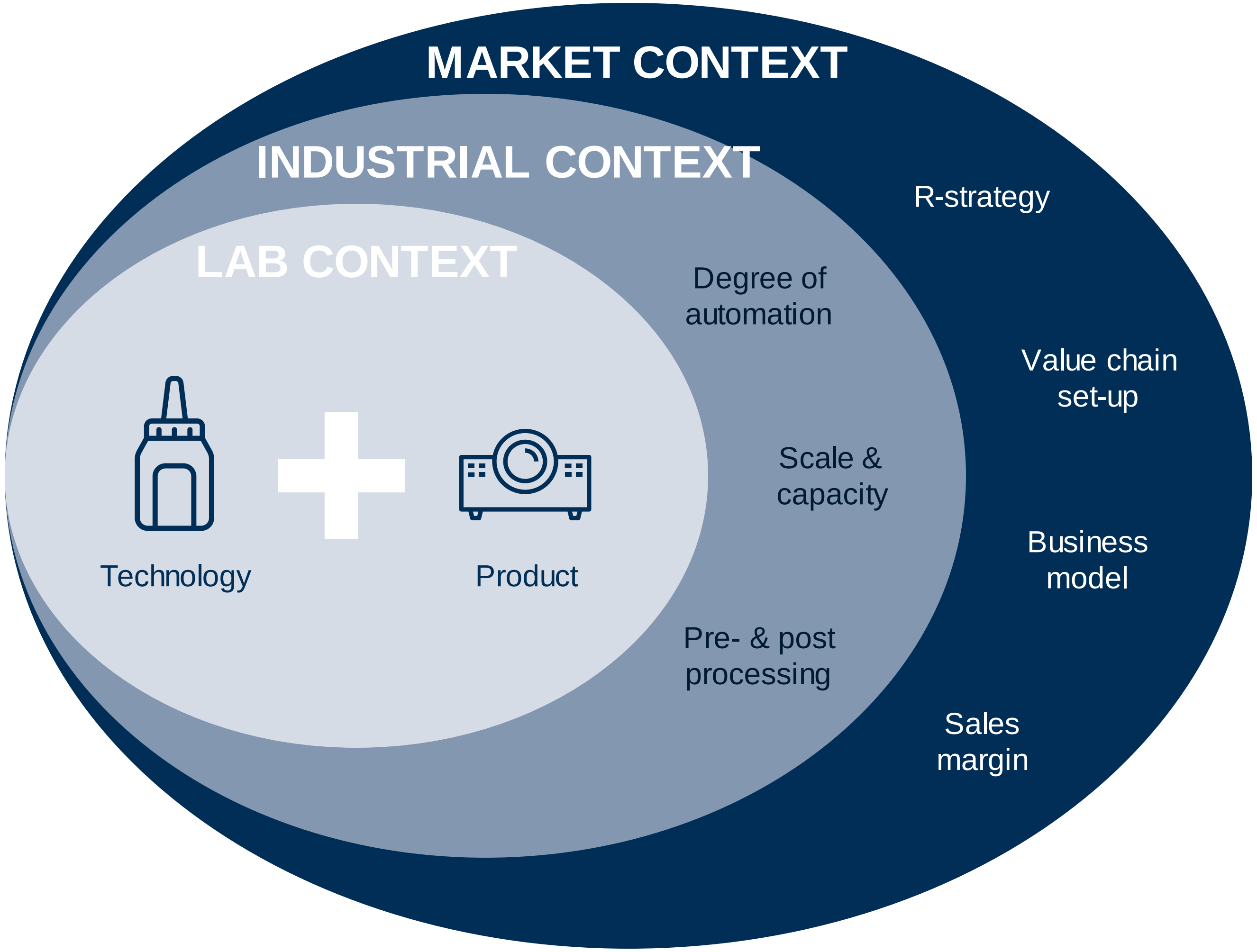
Goal	Circularity assessment perspectives							
	Functionality			Environmental		Economic		
	Adhesive	*Substrates*	*Particles*	*Materials*	*Energy input*	*Price of adhesive (OPEX)*	*Investment need (CAPEX)*	*Post debonding effort*
PRESERVATION SUBTRATE								
Induction	**LOST**	**LARGELY PRESERVED** heat conduction removal of glue residue	**LOST** ferromagnetic particles for non-magnetic substrates	**POTENTIAL ADDITION** of conductive particles in case of non-magnetic applications ✦	**HEAT** (from electricity)	**LOW – MEDIUM** conductive particles in case of non-magnetic applications ✦	**MEDIUM** induction device required ✦	**MEDIUM** removal of glue residue ✧
TEP	**LOST**	**LARGELY PRESERVED** heat conduction removal of glue residue	**LOST**	**ADDITION** of TEP particles	**HEAT** (from electricity or any other source)	**MEDIUM** TEP mixed in adhesive	**MEDIUM** heating device required ✦	**MEDIUM** removal of glue residue ✧
UV	**POTENTIALLY PRESERVED** ✧	**PRESERVED**	**NONE**	**SUBSTITUTION** Different adhesive used	**RADIATION** (from light source powered by electricity)	**HIGH** specialized adhesive	**MEDIUM** UV curing device required	**LOW** clean debonding
Electric	**LOST**	**PRESERVED**	**NONE** Debonding of patches without rebonding	**SUBSTITUTION** Different adhesive used	**ELECTRICITY**	**HIGH** specialized adhesive + conductive patches in case of insulative applications ✦	**LOW** Power supply required	**LOW** clean debonding
Convection	**LOST**	**LARGELY PRESERVED** heat conduction removal of glue residue	**NONE**	**NONE**	**HEAT** (from electricity or other source)	**LOW** All adhesives	**MEDIUM** heating device required ✦	**MEDIUM** removal of glue residue ✧
Microwave	**LOST**	**LARGELY PRESERVED** removal of glue residue	**NONE**	**NONE**	**ELECTRICITY**	**LOW** All adhesives	**MEDIUM** industrial oven required ✦	**MEDIUM** removal of glue residue ✧

CE assessments of debonding methods

- The debonding methods are ranked from low to high for each CE perspective. This ranking can only be considered within each column.
- The table is based exclusively on the debonding process itself, therefore it does not include the credits from the recovered substrate.
- Even though some debonding methods have less environmental and economic strains, we conclude that the benefits from substrate preservation outweigh the debonding demands for all CE perspectives

Holistic circularity assessments must consider the product (substrate), industrial & commercial context

- Adhesives typically make up only a minor part of total material use, total production efforts and total product cost
- Consequently, what counts in a sustainability or circularity evaluation of debonding is not (only) the adhesive or debonding method itself but the ability to disassemble with preservation of the substrate / product / component
- The table (in previous slide) is based exclusively on the debonding process itself, therefore it does not include the credits from the recovered substrate.
- We therefore strongly advice to evaluate circularity of debonding from a product perspective, preferably including the industrial and commercial/market context



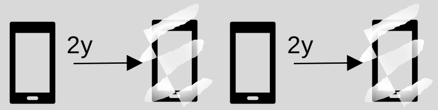
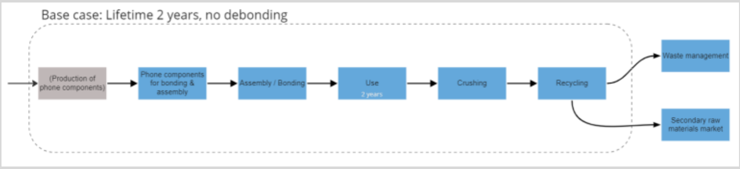
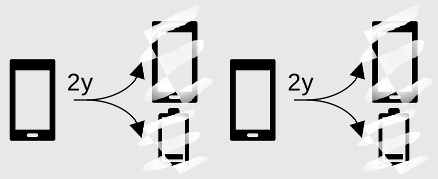
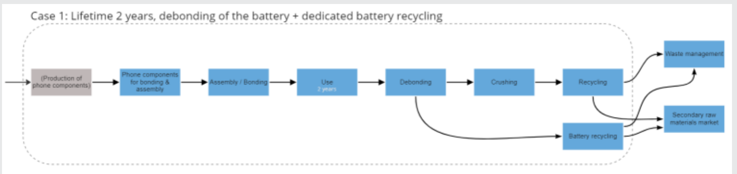
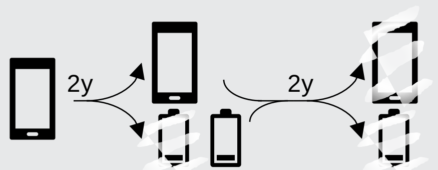
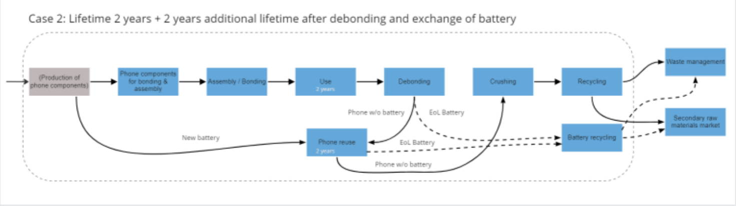
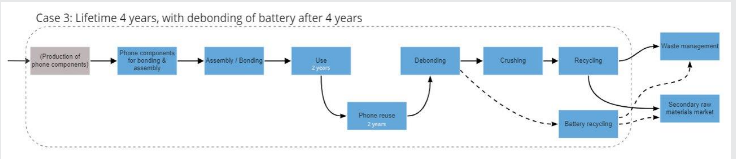
CIRCULAR BONDING

Circular bonding for smartphone

Theoretical case study

vito

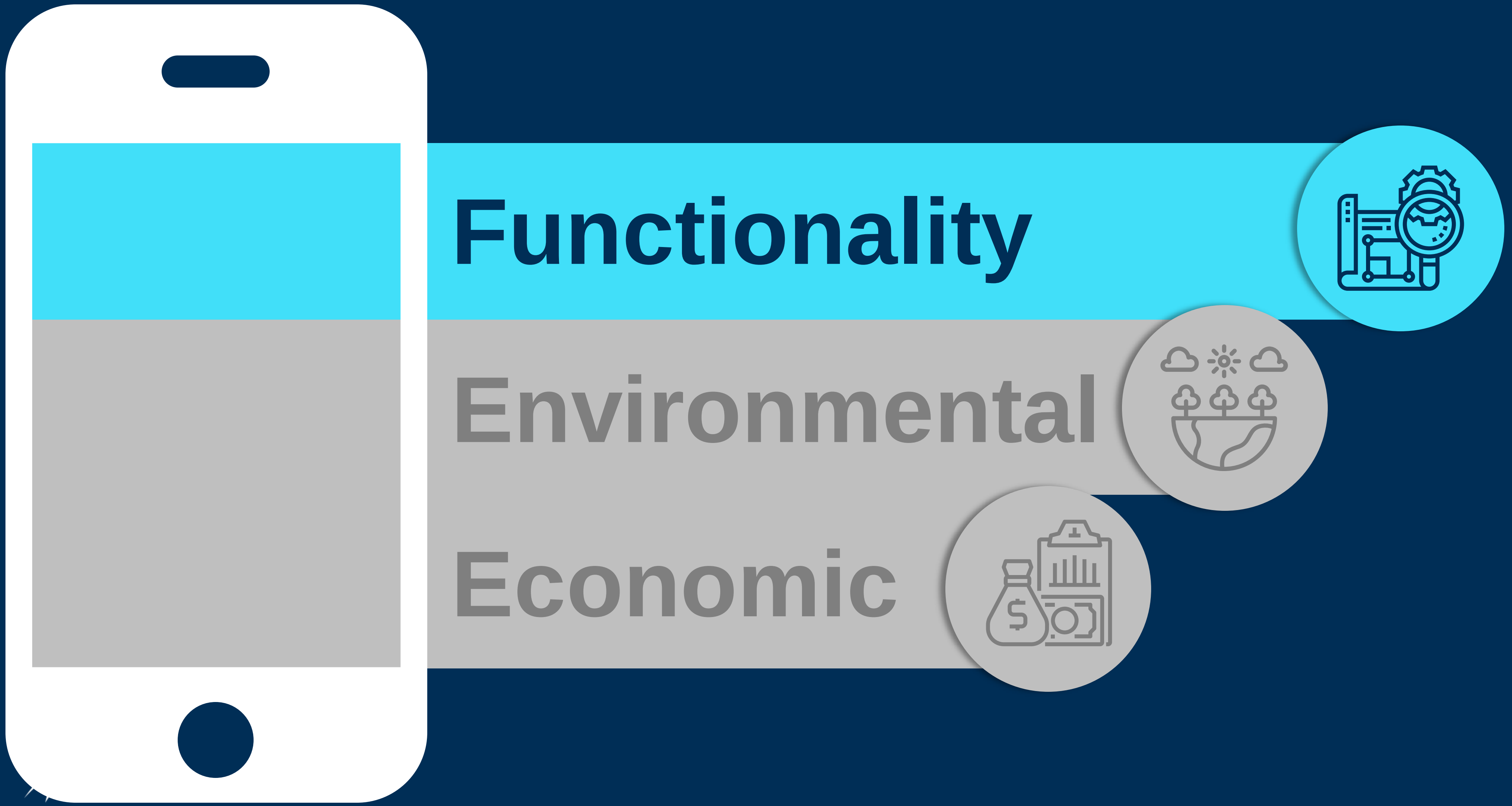
Four different circular scenarios are investigated for the debonding of a smartphone battery…

Scenario	Description		Process chart
a No debonding + recycling (baseline)	Smartphone is used for 2 years and then recycled (as a whole – given no debonding). An additional new smartphone is bought and again discarded and recycled after 2 years		
b Debonding & separate battery recycling	Smartphone is used for 2 years then debonded and battery and rest of the phone are recycled separately. An additional new smartphone is bought and again discarded and recycled after 2 years, with debonding and recycling the battery of the second phone as well.		
c Debonding & exchange of battery	Smartphone is used for 2 years then the battery is replaced and the smartphone (with new battery) is used for another 2 years. The battery of the second phone is also debonded and recycled separately.		
d Debonding & maintenance	Smartphone is used for 4 years (thanks to good maintenance). After 4 years, the battery is debonded and separately recycled.		

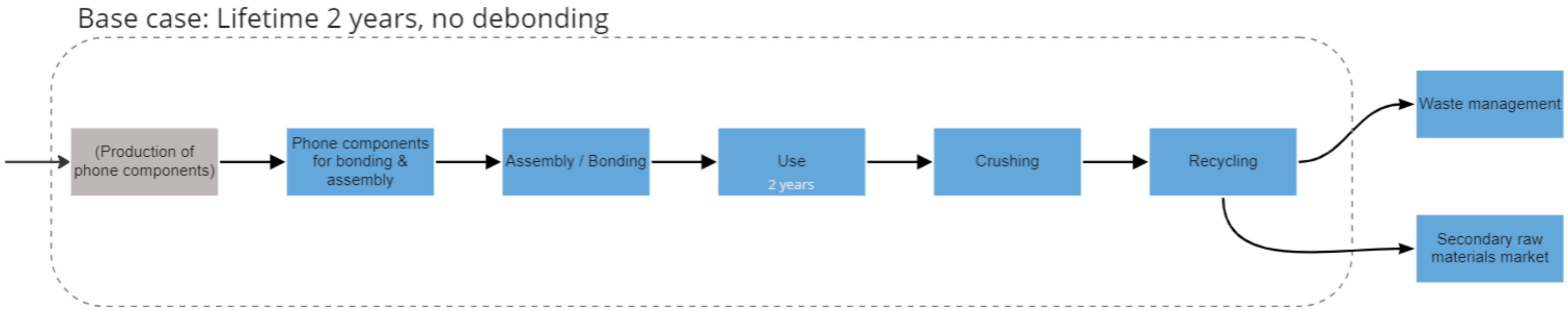
…from three different perspectives.

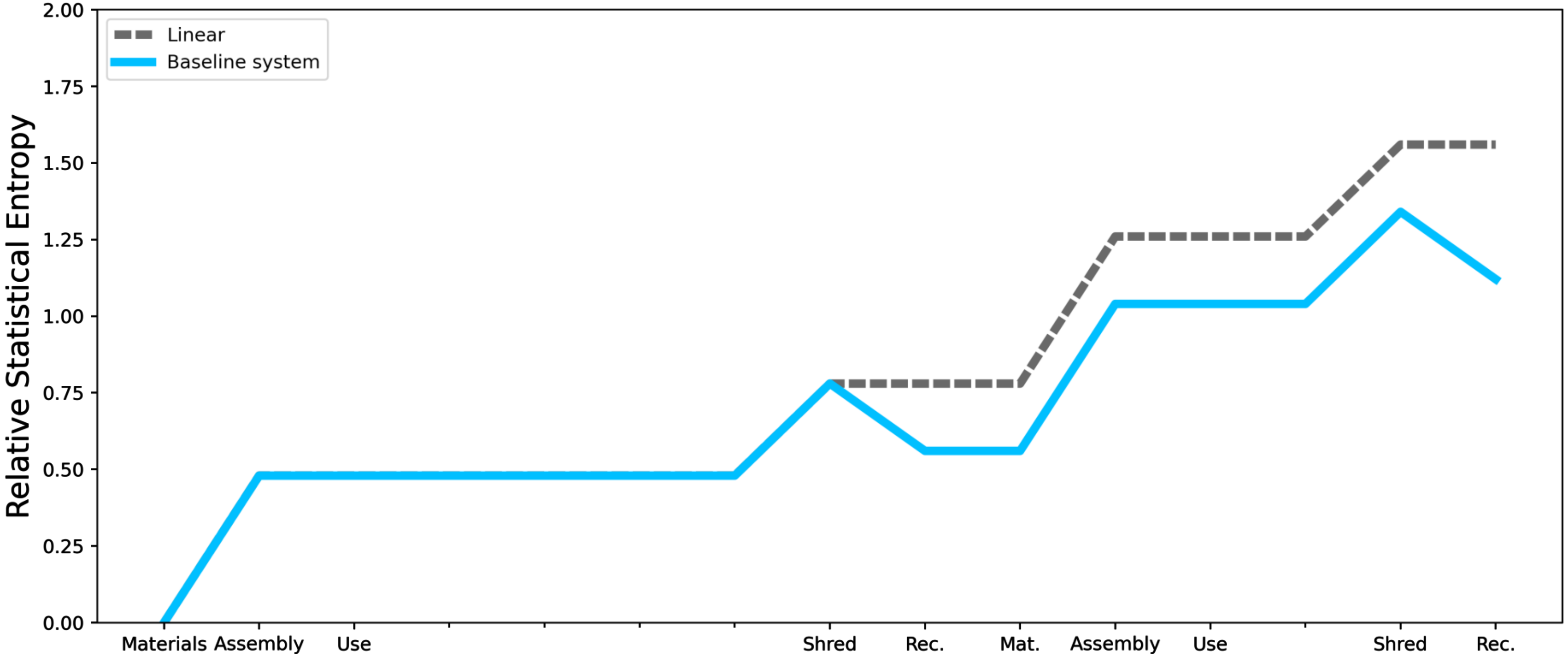
- Functionality
- Environmental
- Economic

…from three different perspectives.



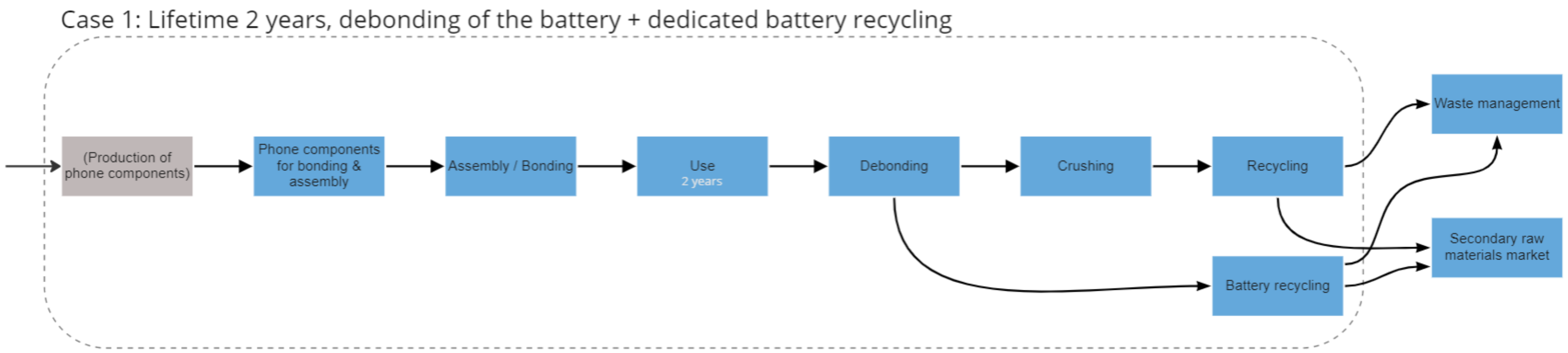
0

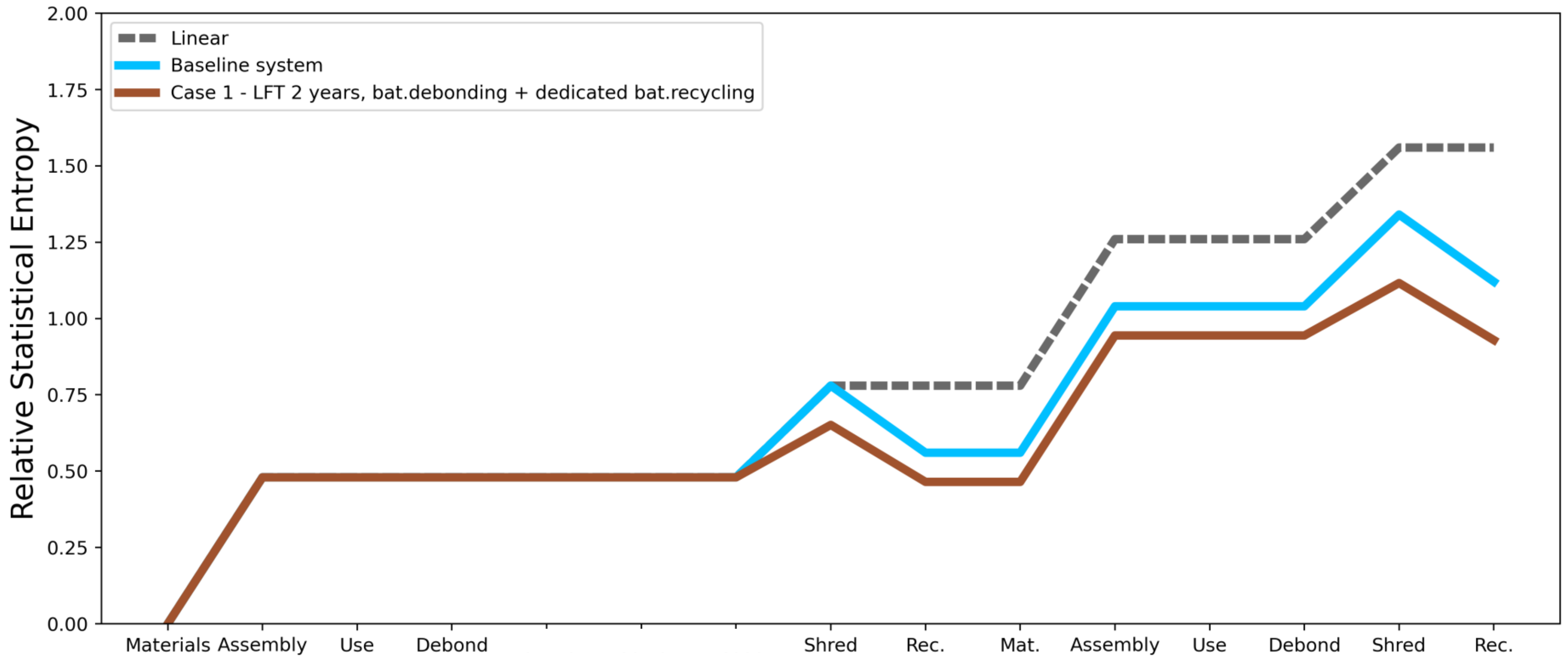




- Limited number of processes in the baseline system
- Reminder: After assembly, the preservation of functionality is indicated by const. RSE values
- Recycling able to reduce RSE to some degree, thereby reducing the distance to ideal system, but being closer to linear system

1



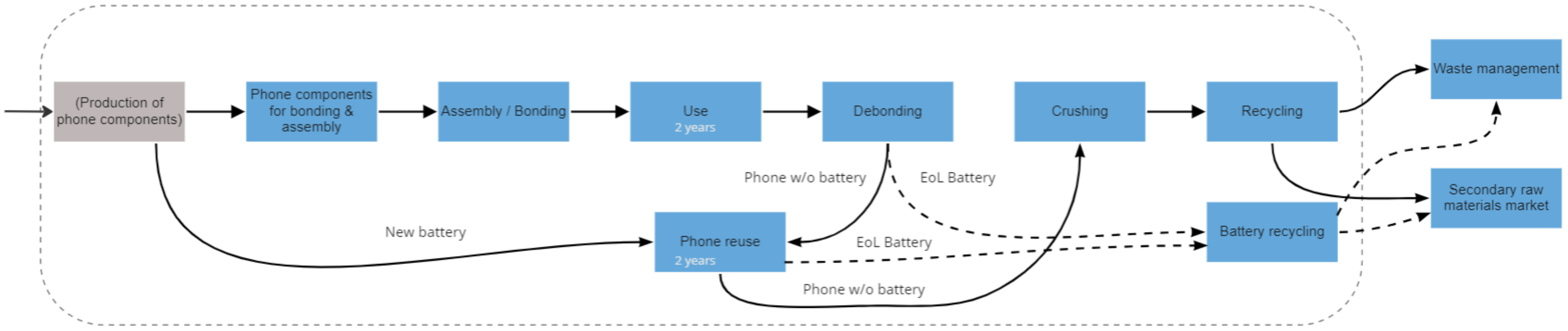


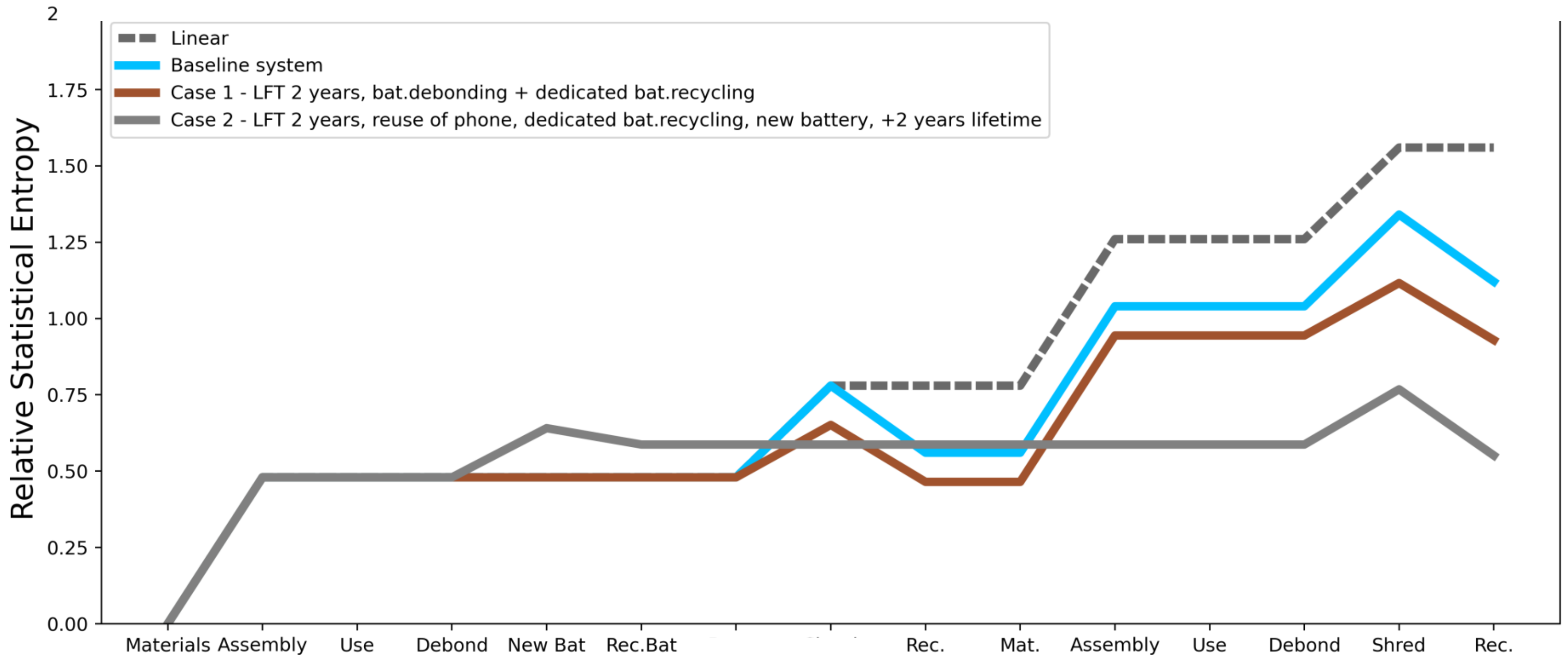
- Battery debonding is added
- Shredding leads to lower RSE increases due to debonded battery (here, 21m% of phone)
- Recycling efficiencies are identical, → lower RSE values achieved by avoiding functionality losses (debonding and dedicated bat.recycling)
- Case 1 shows better performance (further away from linear system, closer to resource effectiveness)

vito

2

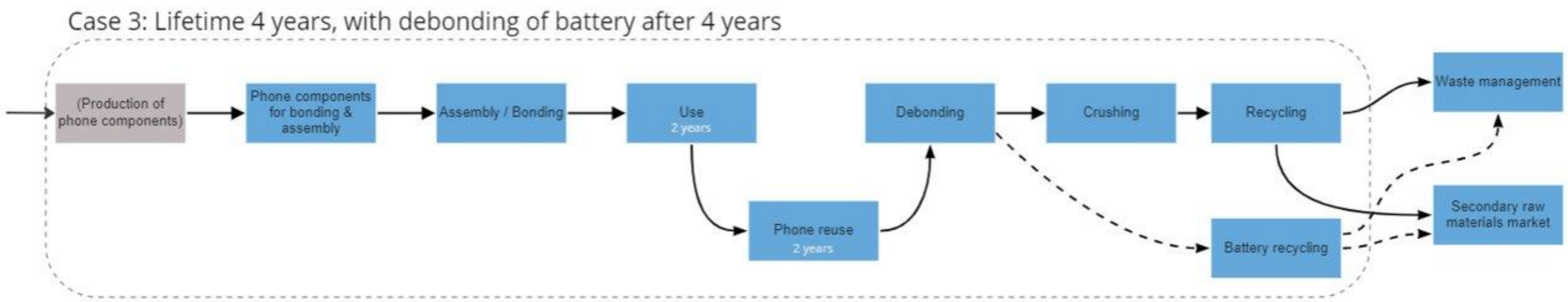
Case 2: Lifetime 2 years + 2 years additional lifetime after debonding and exchange of battery

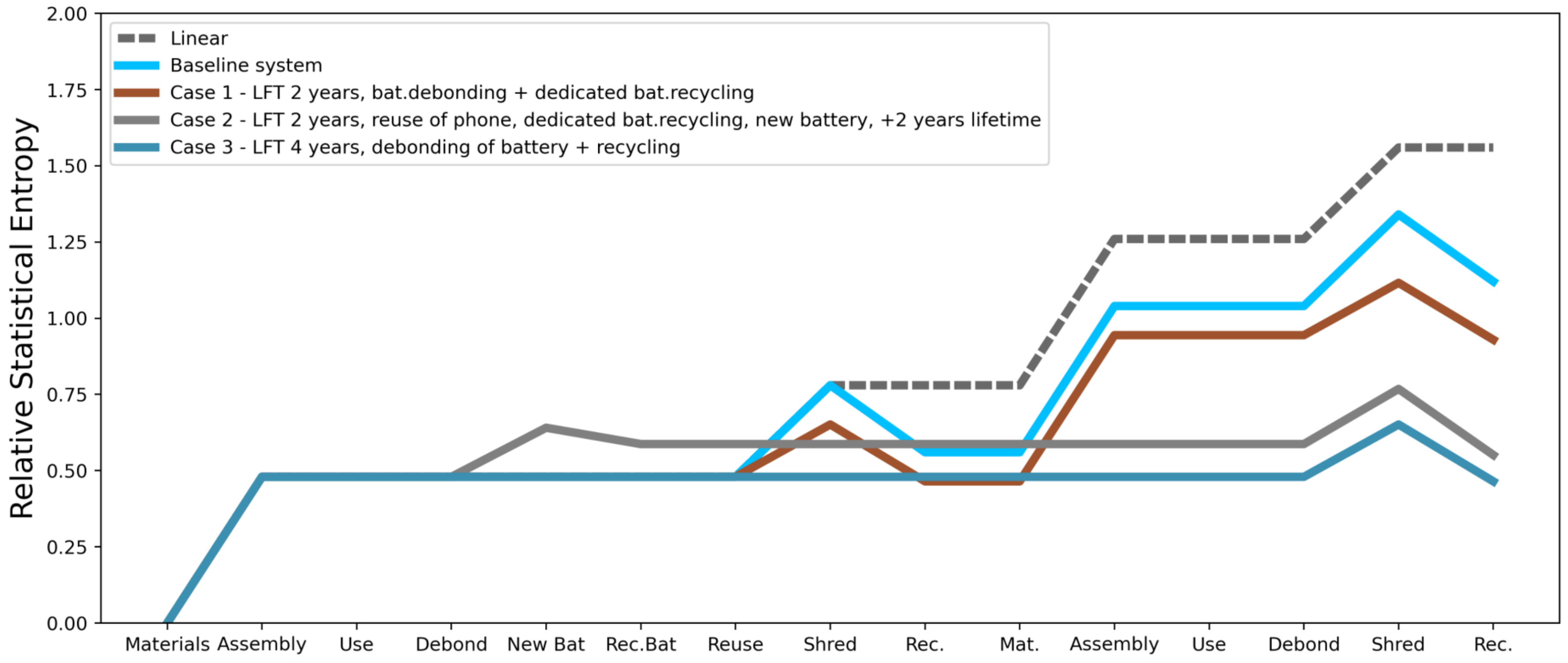




- Debonding of battery and replacing with a new battery as separate steps that allows to reuse the old phone for another lifecycle
- Changes in RSE earlier, but enable the reuse of the phone
- No phone shredding stage in the first lifecycle, keeps the system even closer to resource effectiveness

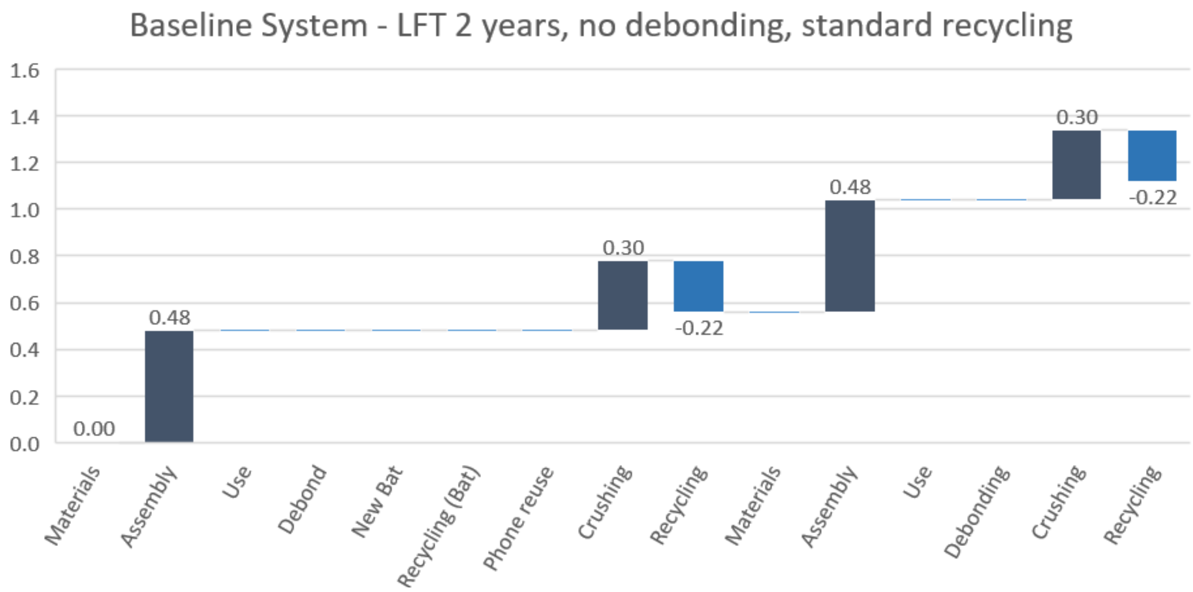
3

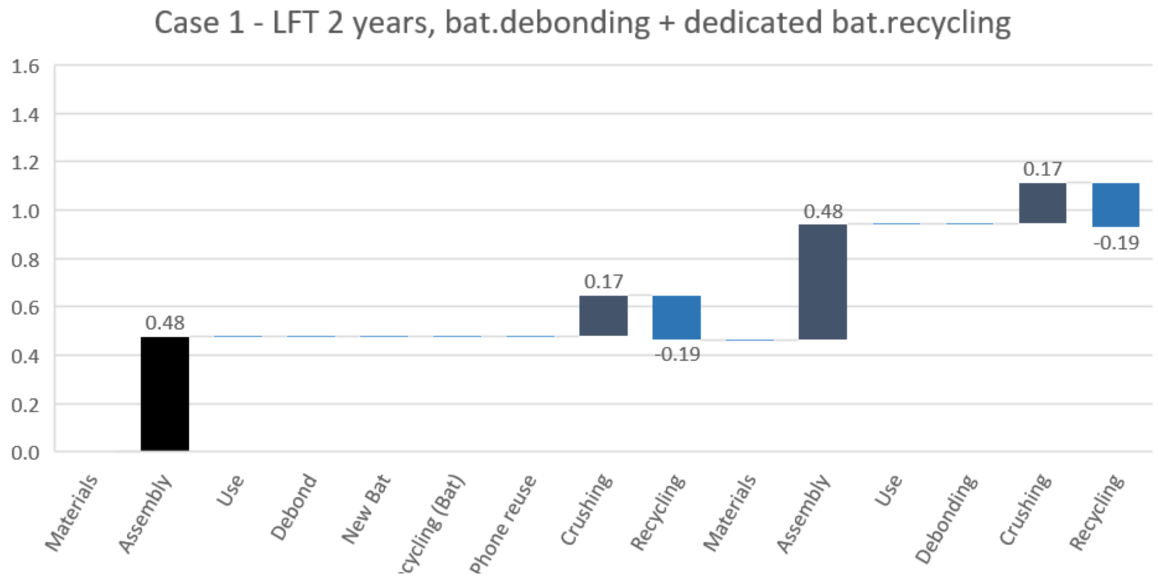


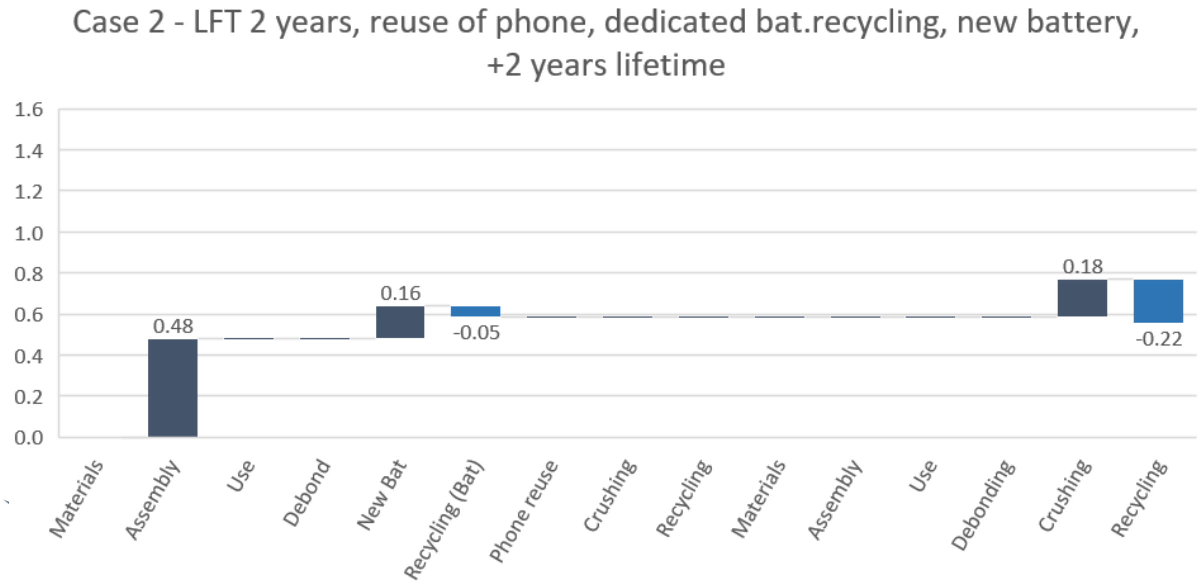


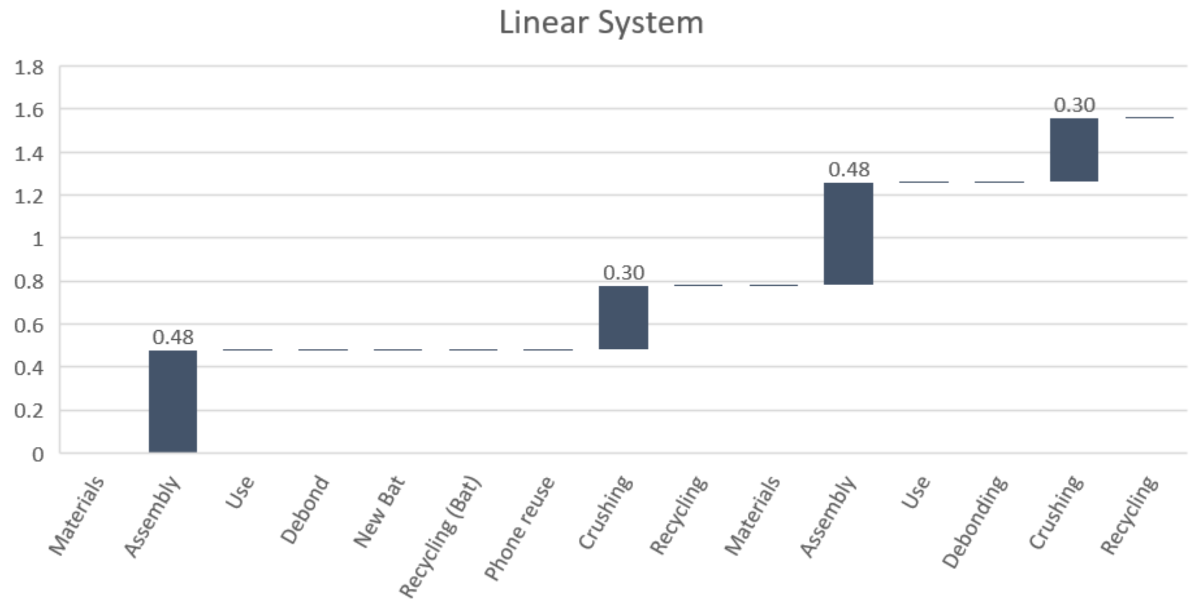
- No processes required to extend the phone lifetime for another +2 years
- Functionality stable over time
- Until 4 years the phone battery is debonded and treated as in other systems

Functionality graphs – different representation

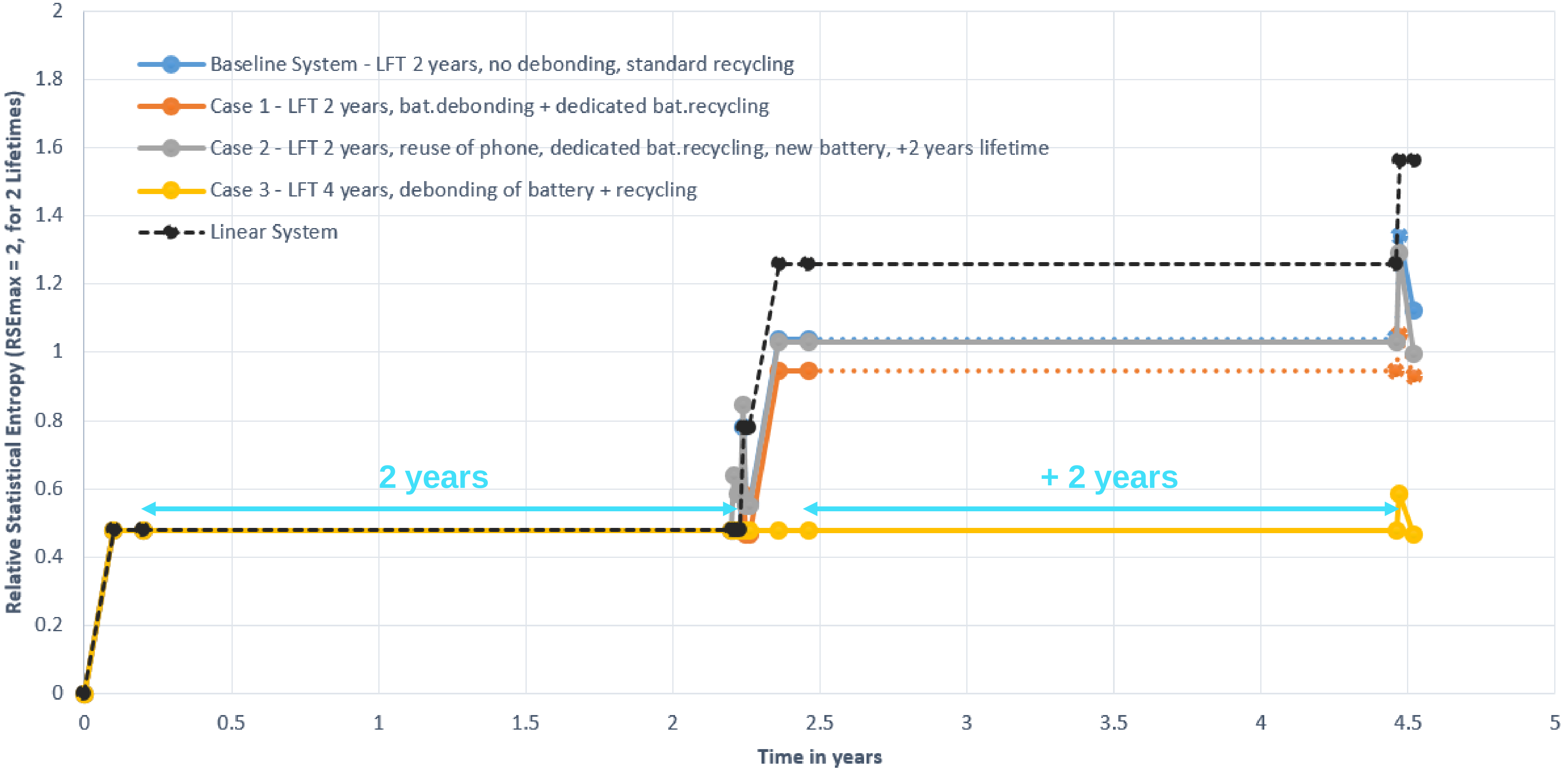






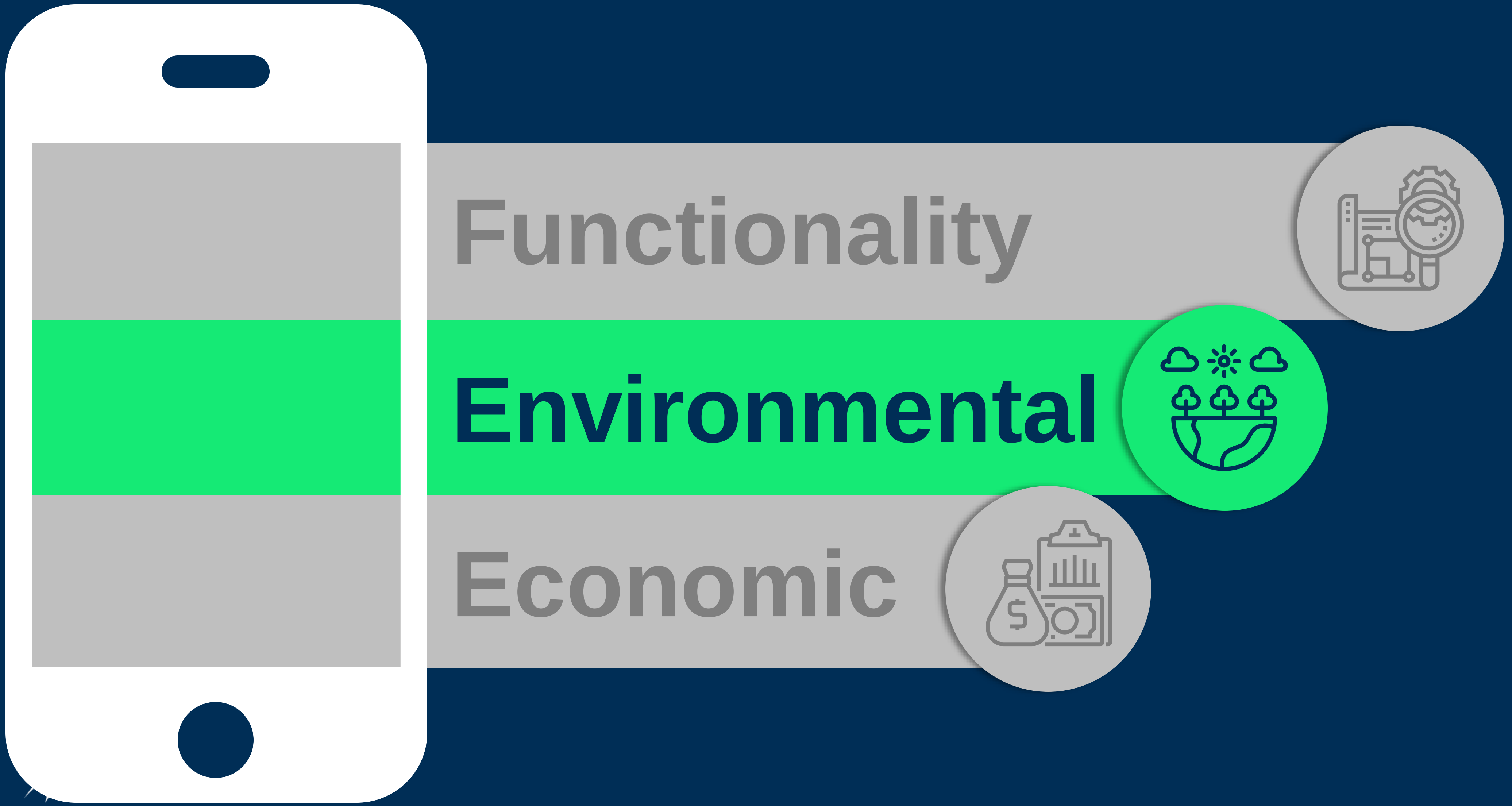


Results – Temporal perspective



- Temporal perspective shows how combinations of processes affect the location of the 'functionality plateau'
- Separate process effects difficult to see
- Also here, functionality preservation represented by absence of RSE increases

…from three different perspectives.

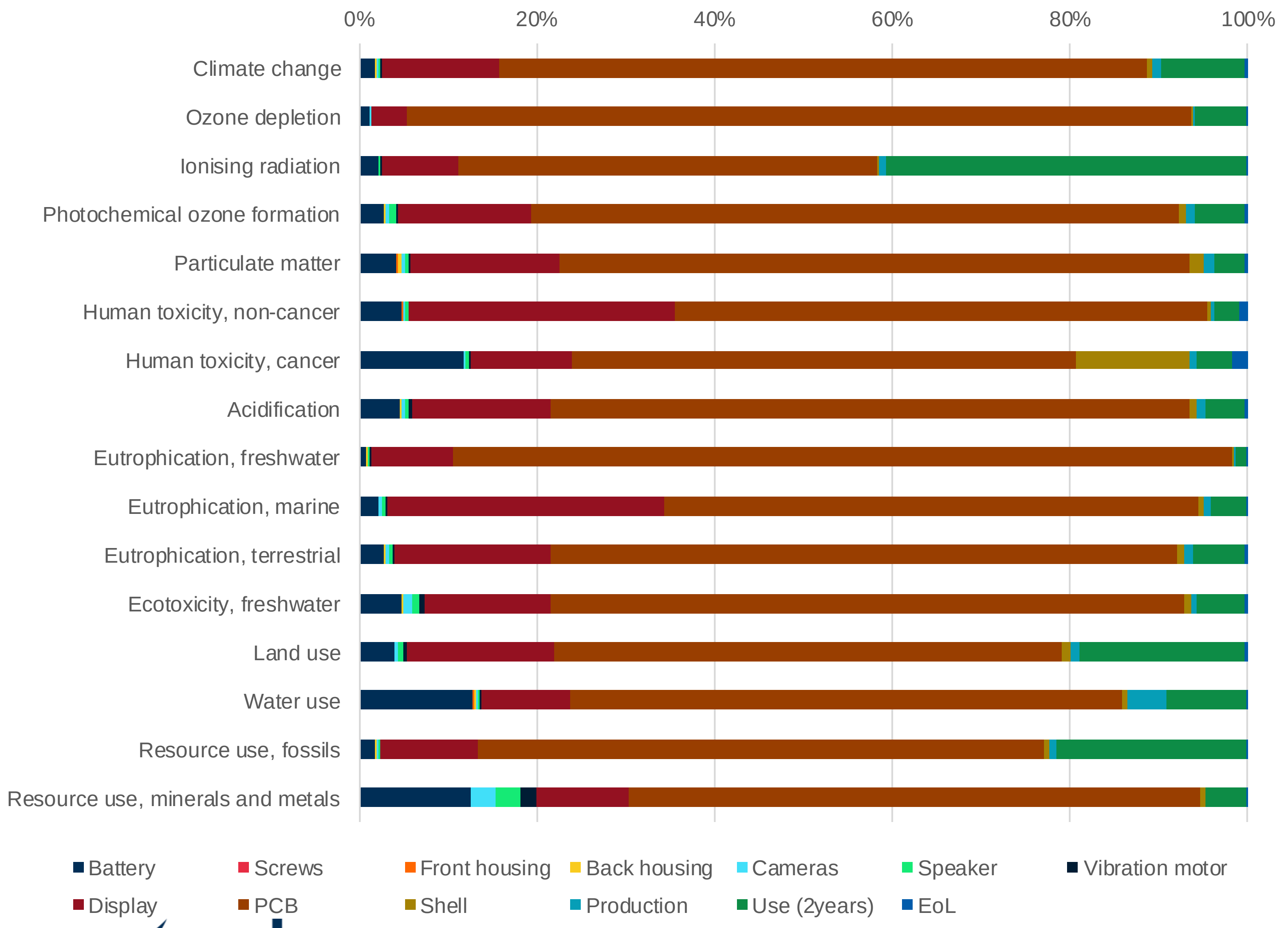


Goal & Scope LCA

- Cradle (raw materials) to grave (recycling to secondary material)
- Based on Ecoinvent database
- Calculation with EF method

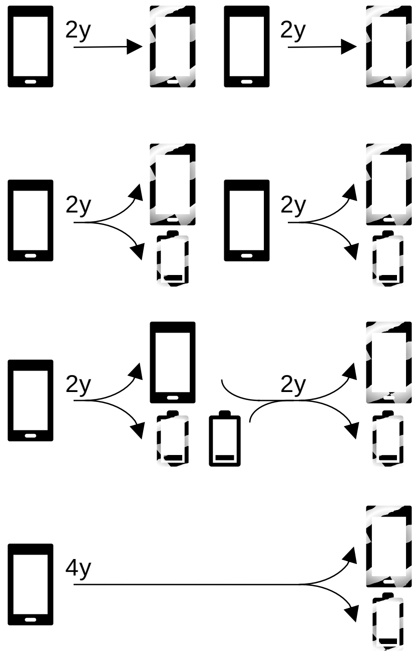
Impact category	Unit
Climate change	kg CO_2 eq
Ozone depletion	kg CFC11 eq
Ionising radiation	kBq U-235 eq
Photochemical ozone formation	kg NMVOC eq
Particulate matter	disease inc.
Human toxicity, non-cancer	CTUh
Human toxicity, cancer	CTUh
Acidification	mol H^+ eq
Eutrophication, freshwater	kg P eq
Eutrophication, marine	kg N eq
Eutrophication, terrestrial	mol N eq
Ecotoxicity, freshwater	CTUe
Land use	Pt
Water use	m^3 depriv.
Resource use, fossils	MJ
Resource use, minerals and metals	kg Sb eq

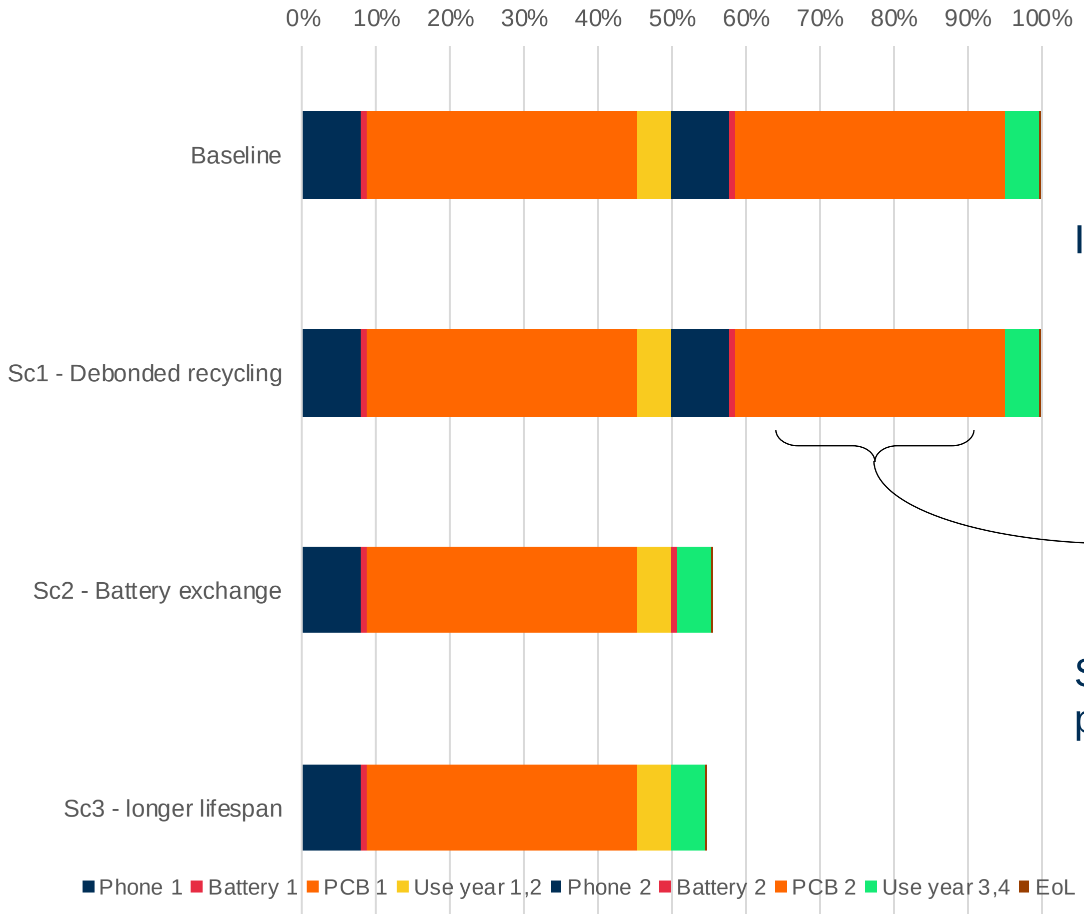
Results baseline



- Production of PCB: main contributor to all impact categories
- Use phase – electricity: high impact on ionising radiation (due to nuclear energy in BE grid mix)

Scenarios – focused on Climate change (CO_2 eq.)





Impact of EoL not visible in total life cycle

Avoided production of phone (esp. PCB)

Small difference between Sc2 and 3 since battery production only contributes for 1%

…from three different perspectives.

Functionality

Environmental

Economic

For a comprehensive economic evaluation of battery debonding for smartphones three perspectives should be looked into

Economic evaluation from three perspectives

MACRO / MARKET PERSPECTIVE

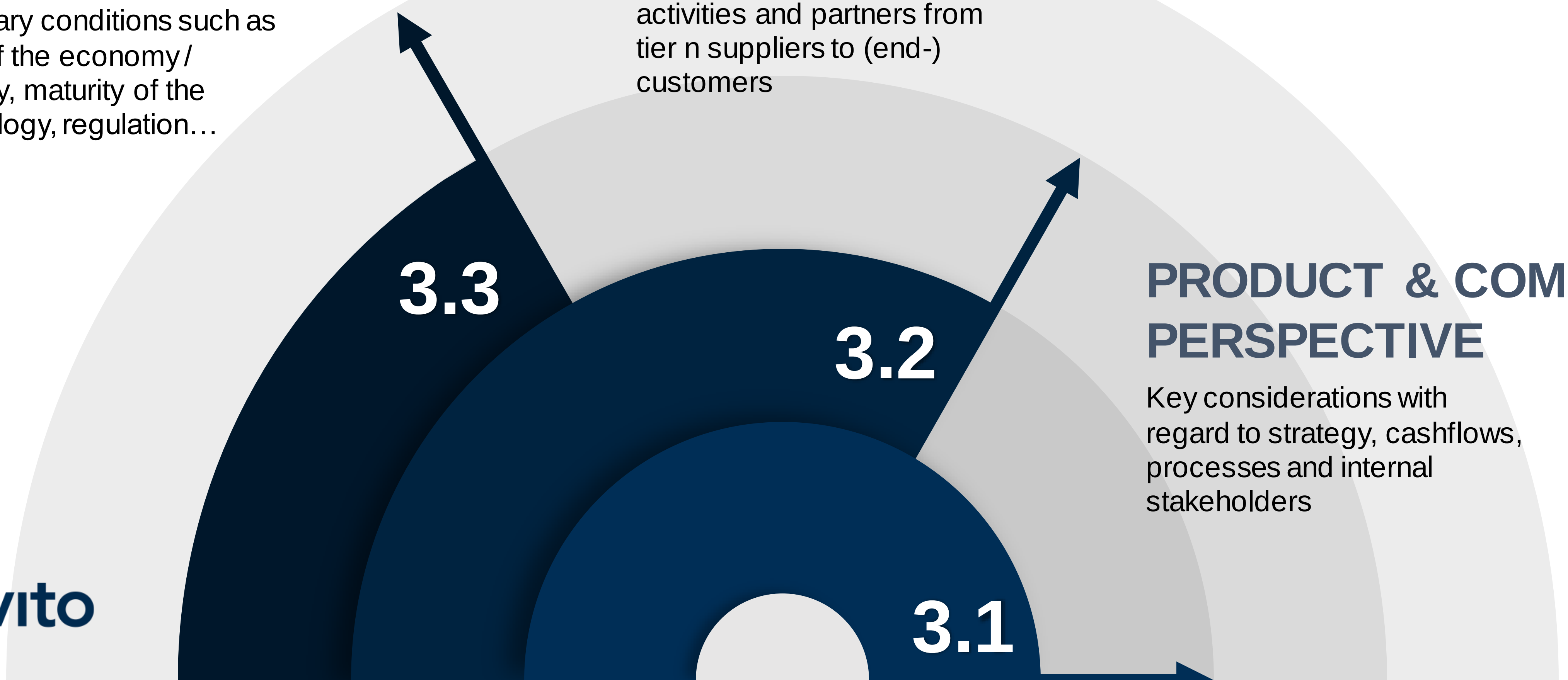
Boundary conditions such as state of the economy / industry, maturity of the technology, regulation…

VALUE CHAIN PERSPECTIVE

Impact on value chain activities and partners from tier n suppliers to (end-) customers

PRODUCT & COMPANY PERSPECTIVE

Key considerations with regard to strategy, cashflows, processes and internal stakeholders



Outcome of the lifecycle cost analysis shows that circular strategies in a lease scheme enabled by debonding are most profitable

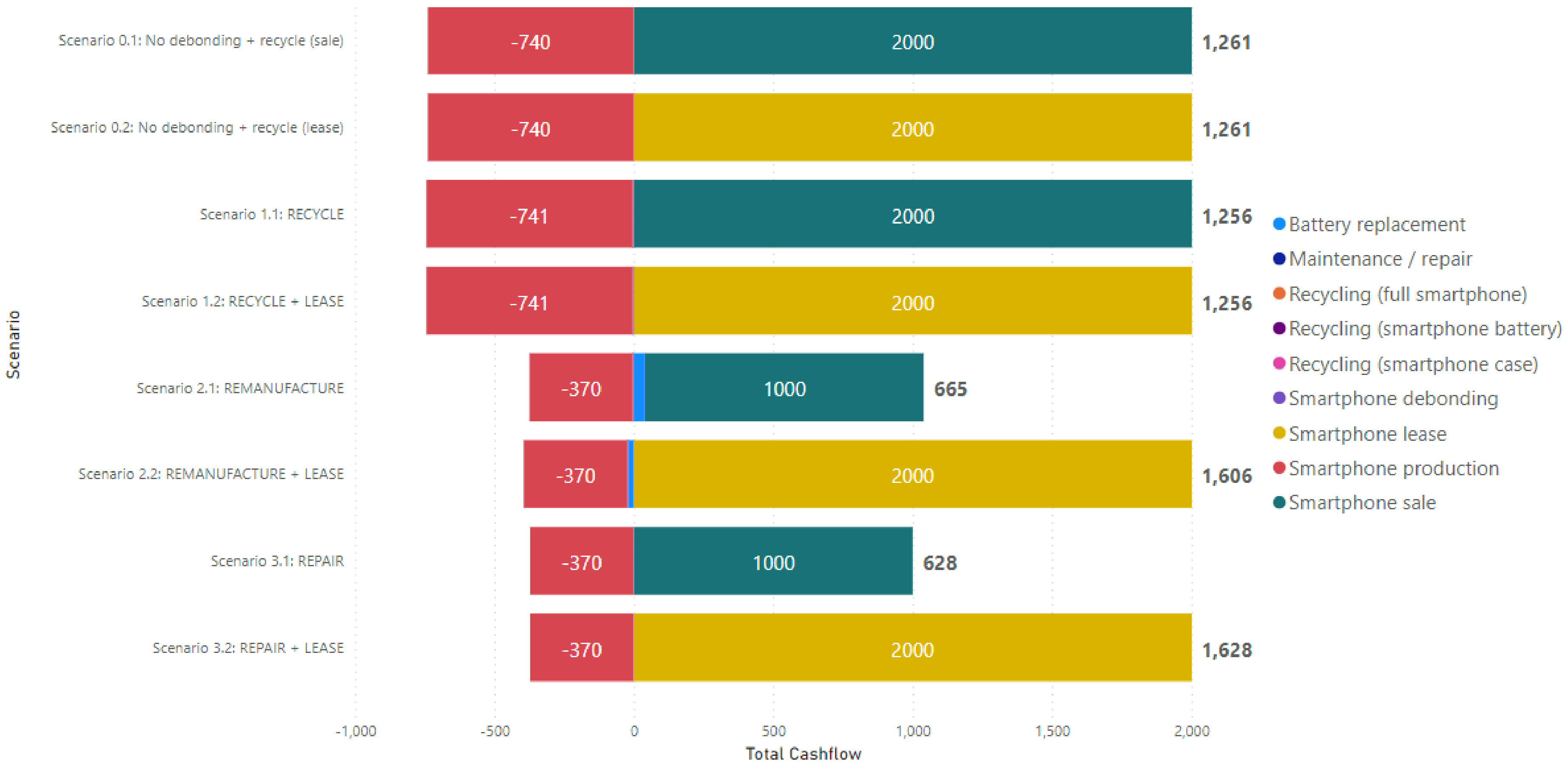
2.1 Product & company level evaluation

	Cashflow per Year	1	2	3	4	Total CF	Delta	%
SC0 (no debonding)	BASELINE (no debonding)	630.09 €	0.55 €	630.09 €	0.55 €	1261.28 €	0.00 €	0%
	BASELINE + LEASE	130.09 €	500.55 €	130.09 €	500.55 €	1261.28 €	0.00 €	0%
SC1	RECYCLE (+ debonding)	629.67 €	-1.48 €	629.67 €	-1.48 €	1256.37 €	-4.91 €	0%
	RECYCLE + LEASE	129.67 €	498.52 €	129.67 €	498.52 €	1256.37 €	-4.91 €	0%
SC2	REMANUFACTURE (battery replacement)	629.67 €	36.98 €	0.00 €	-1.48 €	665.16 €	-596.11 €	-47%
	REMANUFACTURE + LEASE	129.67 €	477.98 €	500.00 €	498.52 €	1606.16 €	344.89 €	27%
SC3	MAINTENANCE	629.67 €	0.00 €	0.00 €	-1.48 €	628.18 €	-633.09 €	-50%
	MAINTENANCE + LEASE	129.67 €	500.00 €	500.00 €	498.52 €	1628.18 €	366.91 €	29%

1. The sale price and lease price are assumed to be equal over a 2-year period

OBSERVATION 1: Bonding and debonding make up only a minor fraction of total smartphone lifecycle costs

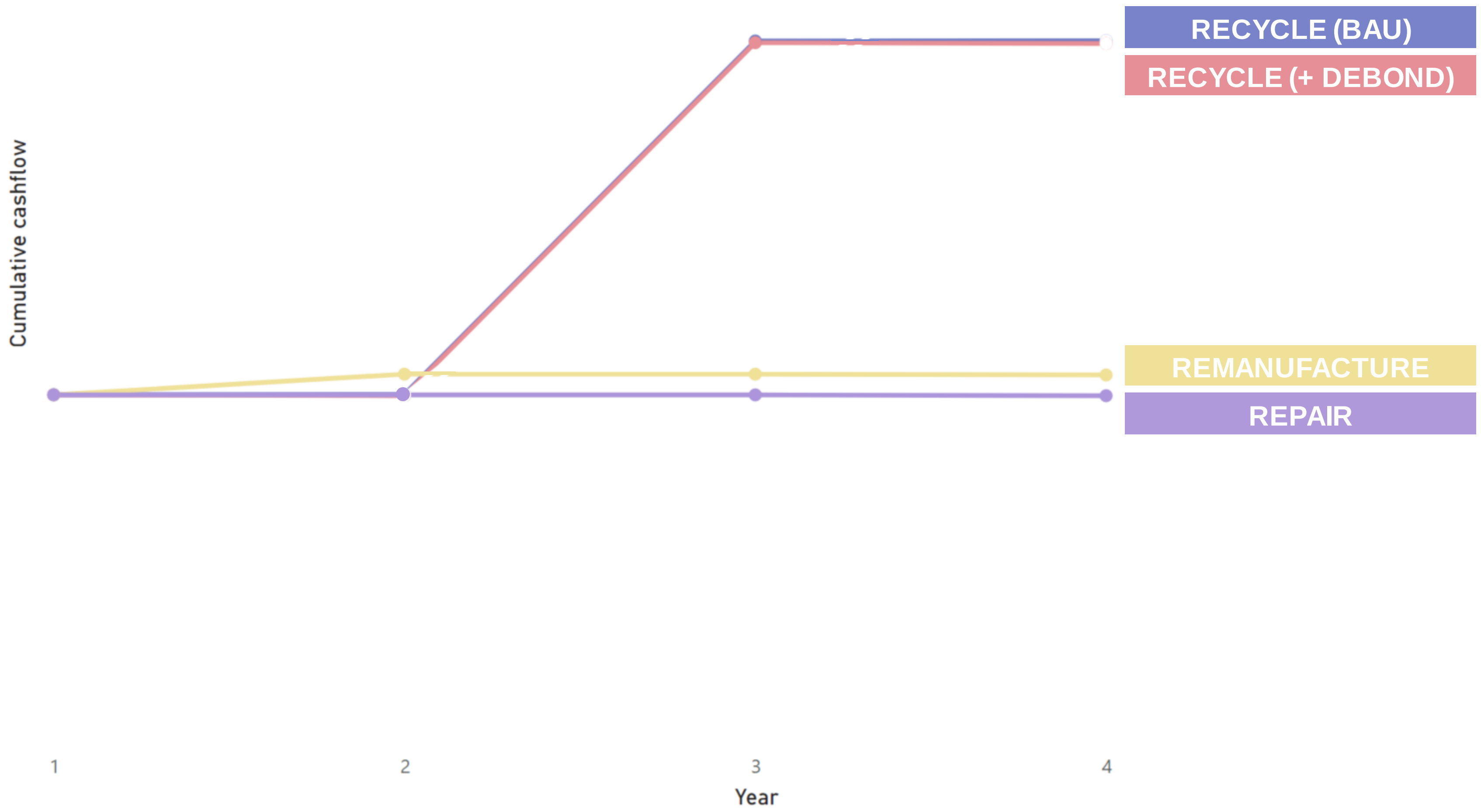
2.1 Product & company level evaluation



- Smartphone bonding with 'debondable adhesives' costs on average €0.43 more (between €0 to 0.72 depending on technology). On a total smartphone production cost of €370 this is negligible
- Smartphone debonding at EoL or for remanufacturing costs on average € 2.20 (between €0.09 and 5.54 depending on technology)

<u>OBSERVATION 2:</u> In a linear system sale is more profitable than lease, when applying circular strategies the reverse is true

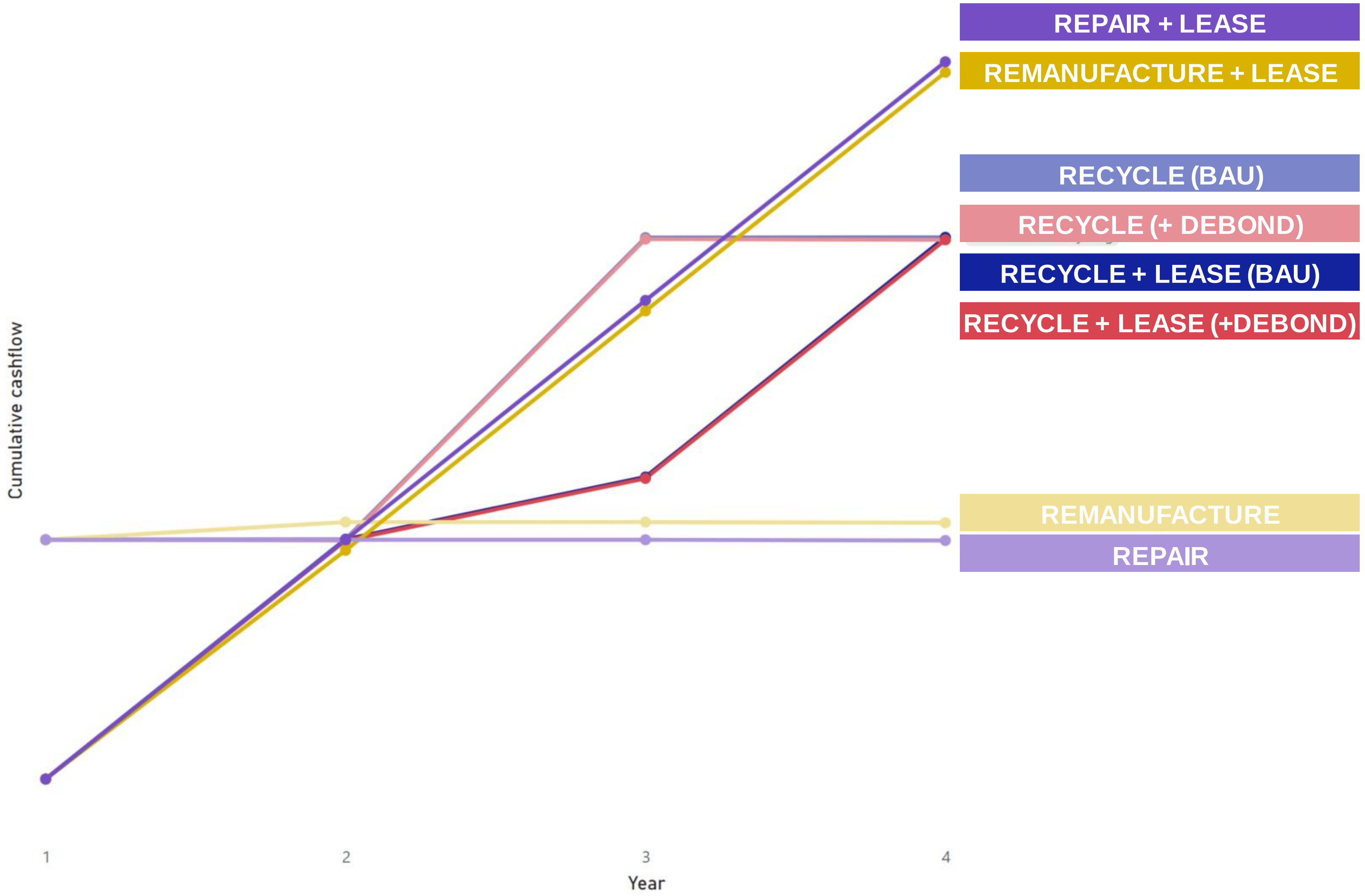
2.1 Product & company level evaluation



- In a linear system, the business as usual scenario comes out on top
- The cost of debonding outweighs the benefit of more efficient recycling in the recycling + debonding scenario
- Remanufacture scenario sees some revenues in year 2 from replacing the battery but this is small in comparison with the sale of a brand new smartphone
- Repair scenario in which smartphone is designed for reparation and maintenance leading to an extended lifetime also does not make sense from a (linear) business perspective

OBSERVATION 2: In a linear system sale is more profitable than lease, when applying circular strategies the reverse is true

2.1 Product & company level evaluation



- If one decides to shift to product-service systems instead of linear sales, the combination with circular strategies clearly outperforms the linear system
- In these scenarios the customer keeps on using the perfectly working smartphone (albeit repaired or remanufactured) over the 4-year leasing period where in the linear scenario after 2 years a replacement is required

OBSERVATION 3: the benefit of separate battery recycling is offset by the additional cost of debonding – these strategies hence require incentivization

2.1 Product & company level evaluation

	Cashflow per Year	1	2	3	4	Total CF	Delta	%
SC0 (no debonding)	BASELINE (no debonding)	630.09 €	0.55 €	630.09 €	0.55 €	1261.28 €	0.00 €	0%
	BASELINE + LEASE	130.09 €	500.55 €	130.09 €	500.55 €	1261.28 €	0.00 €	0%
SC1	RECYCLE (+ debonding)	629.67 €	-1.48 €	629.67 €	-1.48 €	1256.37 €	-4.91 €	0%
	RECYCLE + LEASE	129.67 €	498.52 €	129.67 €	498.52 €	1256.37 €	-4.91 €	0%
SC2	REMANUFACTURE (battery replacement)	629.67 €	36.98 €	0.00 €	-1.48 €	665.16 €	-596.11 €	-47%
	REMANUFACTURE + LEASE	129.67 €	477.98 €	500.00 €	498.52 €	1606.16 €	344.89 €	27%
SC3	MAINTENANCE	629.67 €	0.00 €	0.00 €	-1.48 €	628.18 €	-633.09 €	-50%
	MAINTENANCE + LEASE	129.67 €	500.00 €	500.00 €	498.52 €	1628.18 €	366.91 €	29%

1. The sale price and lease price are assumed to be equal over a 2-year period

Key takeaways

Functionality

- Higher circularity = higher preservation of functionality
- Higher recycling rates do not necessarily lead to higher functionality preservation

Environmental

- Battery makes up only minor part of total impact (PCB is the environmental hotspot)
- Scenarios avoiding production of an additional smartphone (c & d) showing significant gains

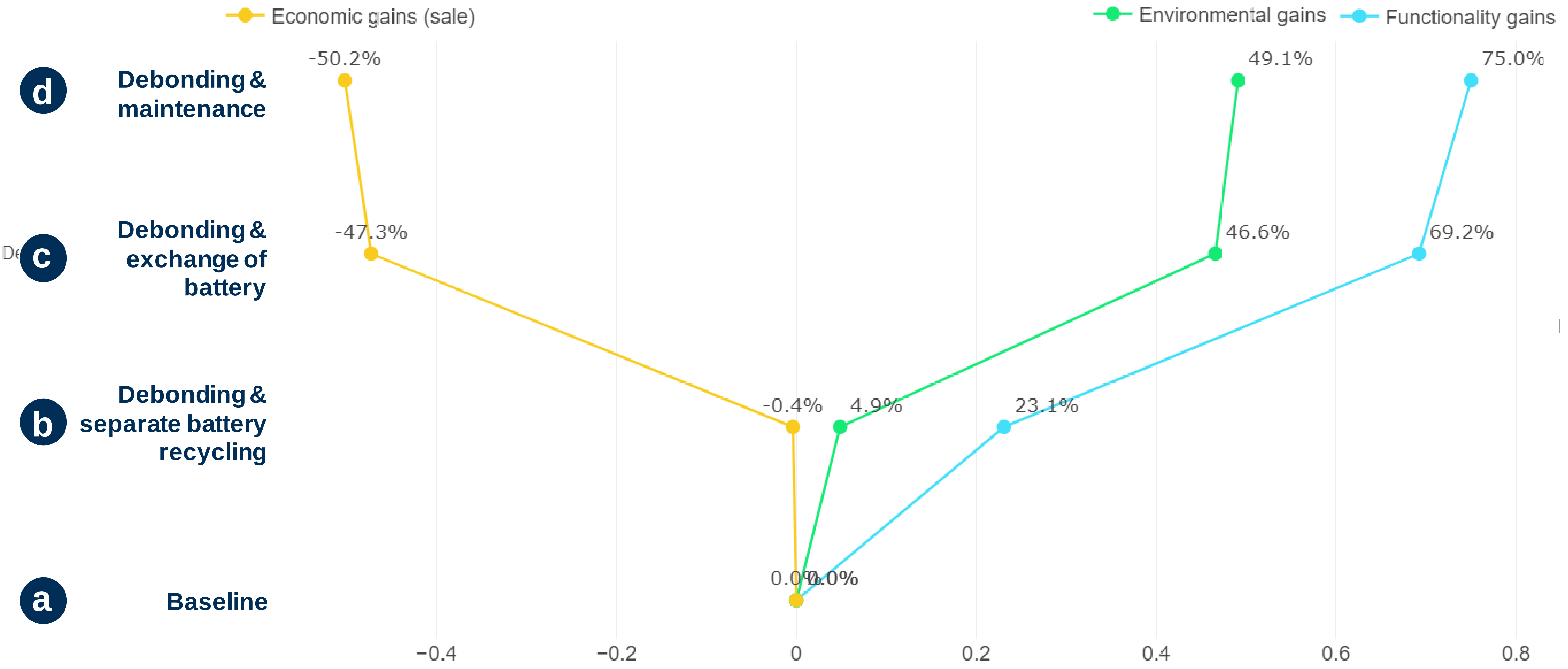
Economic

- Bonding and debonding make up only a minor fraction of total lifecycle costs
- In a linear system sale is more profitable, for circular strategies leasing

CIRCULAR BONDING

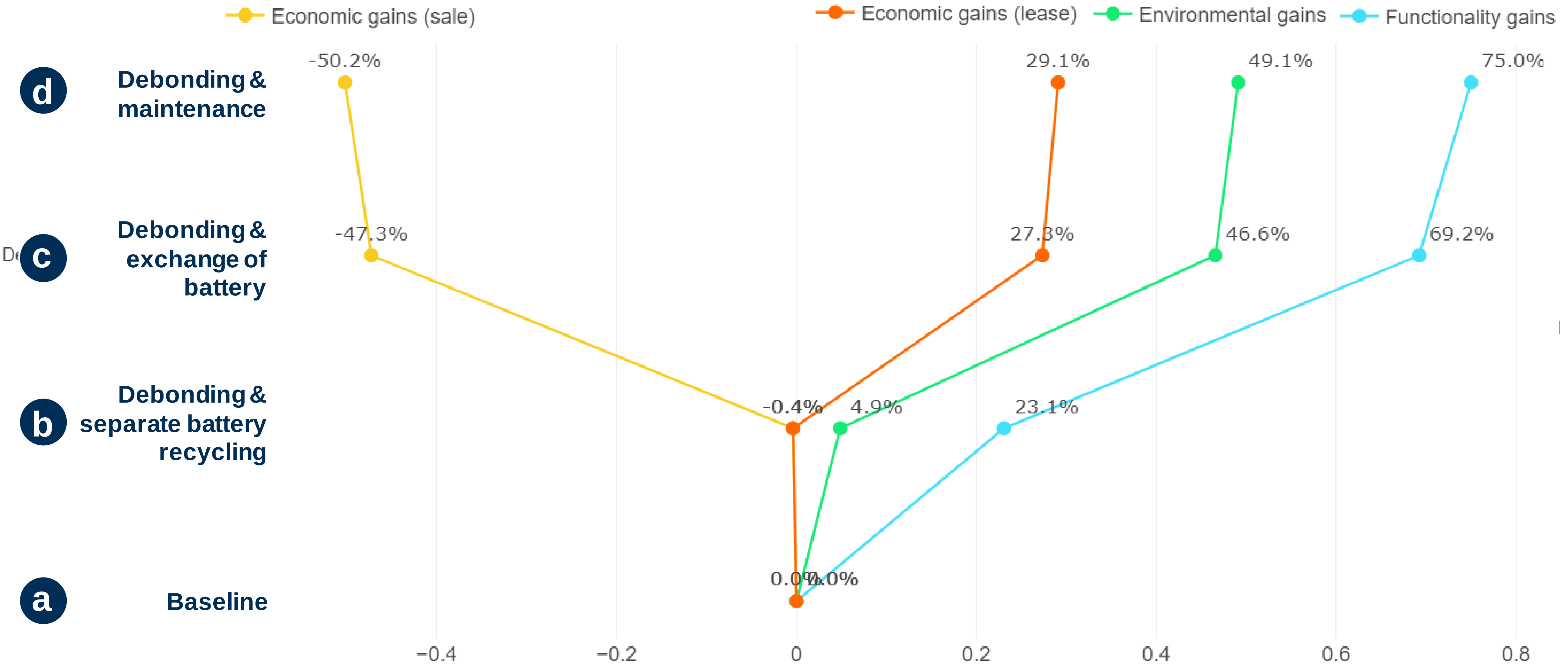
Trade-off between functionality and environmental gains and economic gains…

Summary smartphone case study results



Trade-off between functionality and environmental gains and economic gains solved by introducing circular business models

Summary smartphone case study results

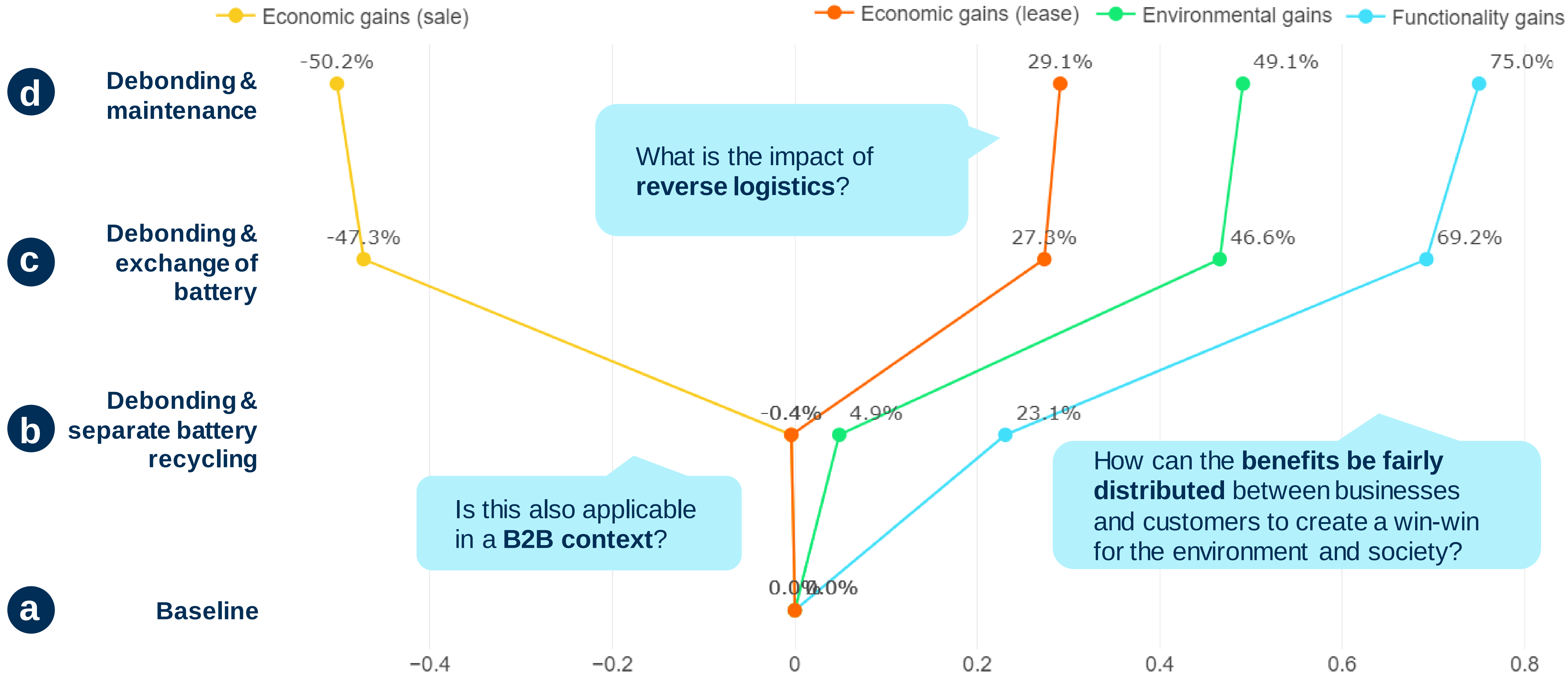


Trade-off between functionality and environmental gains ... ins solved by intro... usiness models

... case study results

Which **policy instruments** can be used to trigger a similar outcome?

What about **customers**' preference for sale over lease?



What is the impact of **reverse logistics**?

Is this also applicable in a **B2B context**?

How can the **benefits be fairly distributed** between businesses and customers to create a win-win for the environment and society?