Product Longevity (i.e. Device Lifetime Extension) and Its Links to Sustainability

An Academic Literature Review

Carrie Snyder, More Than Sustainability

CC-BY-SA 4.0

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Environmental Sustainability

- **Environmental sustainability as it relates to businesses considers the production and consumption of energy and materials and the resulting impacts on all aspects of the planetary boundaries[1] of the biosphere, not just carbon emissions (e.g. biodiversity, ocean acidification, land-use change, etc.)**
- Reducing energy impacts, for example, are usually associated with increasing energy efficiency while transitioning to more renewable energy sources
- For materials, circular economy principles come into play, where academics talk about "slowing, narrowing, and closing" materials flows[2]

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Sustainability and Business Objectives

- Some sustainability strategies - such as making manufacturing processes or the products themselves more energy efficient - are generally seen as a win-win from a business profitability, customer satisfaction, and sustainability standpoint
- Other elements of sustainability, however, might be viewed in some ways (but not all) to be in contradiction to objectives of business growth and profitability — for example, by costing more money to implement
- **This presentation explores how academics, who are focused on reducing the environmental impact of human production and consumption systems, view product longevity**, *regardless of the impact (positive or negative) on business objectives*
- It also presents the academic view where total sustainability impacts — across the total volume of products produced — are important, not just per-product impacts (as businesses normally focus on)

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Defining Product Longevity

- **Product longevity/product lifetime is a device-level measurement for durable goods**
- For example, it is not the measurement of how long a product model is made available for sale by a company
- Instead, "**product lifetime is the duration of the period that starts at the moment a product [device] is released for use after manufacture and ends at the moment a product becomes obsolete beyond recovery at product level**"[3]
- Obsolete is defined as "it is no longer considered useful or significant by its user"[3]
- Thus, multiple users are included in this definition: "Products can have one or more use cycles, but only one lifetime. As long as a product's obsolescence can be reversed, a new use cycle can be started."[3]

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Product Longevity Extension and Sustainability

- Extending product longevity is one of multiple strategies to support the “slowing” of material flows
- **Product longevity — especially maintaining the first customer’s use of the product**[4] **— is seen by many scholars as even more important than recycling**[5,6]
- Although they don’t dismiss the importance of recycling (or reuse for that matter), academics note that “any form of remanufacturing, reprocessing or recycling necessarily requires an injection of additional resources and potentially a degrading of the product functionality or material value”[4,6]
- One academic stated: “**[Product] durability is one of the most obvious strategies for reducing waste and increasing material productivity**"[7]

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Basic Logic of How Extending Product Longevity Creates Increased Sustainability

Devices used for longer
(for any reason: better design, change in customer purchasing and care behavior, etc.)

→ Less devices used by a consumer over time to get their same needs met

→ Less total negative environmental impacts from device production and use (summed across the entire customer base and over time)

- For example, if all users replace their products half as frequently, then the environmental during the product production, transportation, and recycling phases are halved (but likely not the customer use phase - e.g. the energy required to charge an electronic device, or the hot water needed to wash clothes)
- **This benefit might be reduced — but not likely cancelled — by the impacts of repairs and maintenance (e.g. battery or screen replacement) that come from using a product for longer**[8,9]
- We're now going to go into some of the complexities (exceptions) to this general logic

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Complexity #1: Release of More Energy Efficient Models

- Sustainability professionals and academics generally look at environmental impacts across four phases: production, transportation, customer use, and disposal
- In this complexity, electrical/electronic product categories with newer models delivering energy efficiency improvements during the customer use phase may show benefits from earlier, rather than later, device replacement
- Note: while GWP/carbon emissions may be reduced overall through early product replacement, other impact categories (such as human toxicity, freshwater ecotoxicity) may increase from new production of the replacement product or the recycling/disposal of the old product[10]

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Complexity #1: Release of More Energy Efficient Models (cont.)

- Studies indicate this complexity has been found to mostly be present for large appliances like refrigerators[11] where the customer use phase dominates the environmental impacts, but not for laptops and smaller (less energy-using) devices[4,12,13]
- Overall this impact depends on actual product lifetimes, and in some studies it was indicated extended product longevity is the best strategy no matter the product category[14]
- This conclusion might need to be revisited, however, if a significant reduction in energy consumption were planned for a next generation product

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Complexity #2: Over-engineering Durability

- While some of extended product longevity is controlled by the consumer (e.g. upgrading to the next generation of product less frequently, getting a product repaired rather than replaced, treating the product with care and not breaking it, etc.), the design of the product (both HW and SW) itself clearly also importantly influences how long a device can be used
- For example, **in a survey of consumers in Western Europe, it was found that consumers said that "Loss in original performance" was the most influential reason for replacing smartphones, although "Time for a new product" came in second**[16]
- Companies can help extend product longevity by designing products to be more durable, but it is possible that this durability can be "over-engineered," given actual consumer behavior[17]
- **In the worst case, increased negative sustainability impacts from using more durable materials — without a corresponding increase in consumer product use time — could in fact make overall sustainability impacts for the product worse, not better**[18,19,20]
- Careful modeling (and influencing!) of consumer behavior can help inform the best product design decisions from a sustainability impact[21]

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Complexity #3: Rebound Effect(s) - Background

- This is one of the most important complexities academics are studying with regards to sustainability, but also one of the most difficult to calculate
- It broadens the boundaries of the systems studied and includes questions like how cost savings influence consumer behavior
- Specifically, **the rebound effect "is a divergent outcome or effect from the intended benefits caused by a systemic response to efficiency or technological change."**[22]
- **"This means that although introducing more efficient equipment or processes may generate energy savings or increase productivity, the rest of the system (producers and consumers) react to this change, increasing consumption and production**"[22]
- One example from energy use is where a more efficient HVAC system is installed in a house, and the energy cost savings are simply spent by the family on setting the thermostat to a more comfortable temperature, partially or fully cancelling out any energy use reductions
- Rebound effect considerations can go even beyond households to indirect industry- or economy-level effects

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Rebound Effects Aren't Always Considered

- Given the broad scope of rebound effects, estimates, too, can be quite broad (e.g. "30-100%"[23])
- **This uncertainty, and also a lack of knowledge about rebound mechanisms, means that many stakeholders — including some academics, businesses, and even governments — have shied away from accounting for the rebound effect in their sustainability calculations**[22]
- In addition, tools such as life-cycle assessment (LCA) may not be designed (or executed in such a way) to easily account for rebound effects[24,25,26]
- Nonetheless, we shouldn't let this uncertainty deter us from paying attention to the rebound effect
- **If our intention with sustainability is to truly operate within the planetary boundaries while supporting human needs, then the rebound effect shouldn't be dismissed**
- An increasing amount of scholarship on the rebound effect (now for materials and not just energy) has been recently coming out of academia. We'll review some of that now.

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

History of Rebound Effects

- The rebound effect was first described in 1865 by William Jevons[27]
- Jevons postulated that an increase in efficiency in the use of coal didn't necessarily lead to less consumption of coal overall. At the time his arguments were largely dismissed without empirical data available to back them up[28]
- This idea — that the energy efficiency gains might be totally cancelled out by greater consumption — was later dubbed the "Jevons Paradox"
- Since then, most sustainability-related rebound effects studied continued to focus on energy consumption (e.g. the idea that increasing the fuel efficiency of cars can actually lead to increased overall CO2 emissions)
- **In 2017, a paper called "Circular Economy Rebound"[29] helped kickstart the academic discussion of rebound in materials, pointing out the possibility where "secondary production [i.e. reuse, product lifetime extension, etc.] does not fully displace virgin raw materials"**[28]

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Non-energy Examples of the Rebound Effect from Academia

- "In a case study, academics evaluated the effect of a conversion to higher efficiency irrigation systems and found that the intended reduction in groundwater use did not occur, partly because of shifting crop patterns toward more water-intensive crops. Other researchers found high additional water consumption due to the expansion of irrigated land, leading to backfire[27]"
- "Overall, two studies found water rebound in the order of 60–70% for China following improvements in irrigation technology. **Another paper found a water economy-wide rebound effect of just over 100% for Spain, meaning that efficiency improvements in water use did not lead to reduced water consumption at the national level**"[27]
- **A study in 2023 in North Carolina found that "solid waste generation increased by 6–10% in the presence of curbside recycling"**[30]
- One paper points out: **"The crucial issue remains the extent to which secondary production can displace primary production. The extent to which this displacement can occur is dependent on market forces, which involve the response of buyers and suppliers to prices, as well as the willingness of buyers to switch to secondary products"**[28]

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Study on the Rebound Effect for Electronics

- **The availability of a market for used products is often seen as an enabler of extended product longevity, and as such, an enabler of improved sustainability outcomes**
- A study was conducted about the used smartphone market in 2018 by Makov (Yale University) and Font Vivanco (University College London)[23]
- **The researchers explored two main rebound mechanisms: (1) imperfect substitution between "re-circulated" (recycled, reused, etc.) and new products and (2) re-spending due to economic savings**
- The study focused on used Apple smartphones sold on eBay within in the US, supplemented with a consumer survey about used smartphone purchase behavior (specifically, what they would have done if the specific used smartphone they purchased wasn't available)

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

The Rebound Effect for Electronics (cont.)

- From this, **they calculated the overall change in GHG emissions from used smartphone sales and found that 27-46% of expected environmental benefits in this category could be canceled out by these two rebound effects**
- They further estimated that if the model were expanded globally to account for the fact that many used smartphones are sold in developing countries (thereby increasing the overall user base), the rebound effect would be almost 80% for 3 of the 4 phone models studied
- **Overall, they postulated in that it is possible the rebound effect from the used smartphone market could be over 100% of the GHG savings (the so-called "backfire" effect)**
- While all studies involve estimates and assumptions, these findings and others indicate that rebound-type effects are very important to consider when we want to achieve *actual positive environmental impacts* (and not just an illusion of them)

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Greater Responsibilities

- **The limits of planetary boundaries implies that it is not enough simply slow down negative environmental impacts, we must actually stop these impacts before reaching the irreversible "cliffs" of system collapse (if we haven't surpassed them already)**
- From this ecosystem-wide perspective, academics are showing that businesses simply reducing per-product impacts (while ignoring increasing sales volumes, e.g.), is not enough for humanity to stay within planetary boundaries
- Instead, the entire system of production and consumption must drastically reduce its total environmental impact
- The evidence of rebound effects, however, indicate the significant complications and challenges of this "stopping" task **— it is possible our efforts to create sustainability are not at worse neutral, but can in fact backfire and make our impacts on the environment *even worse***
- **There are frankly no easy solutions or fixes to this reality, but indicates the need for us to take even greater responsibility for the actual (i.e. not assumed, or hoped for) outcomes of our sustainability initiatives**

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Summary

- **Academics have for some time identified a clear link between increasing product lifetimes and improving sustainability, and see product longevity as a key factor for the sustainability for durable goods** (even more than recycling)
- **The overall logic is that by increasing lifetimes of products, less materials and energy are consumed to meet the same consumer needs**, therefore mitigating environmental impacts
- Academics have been more recently studying, however, identify several complexities that need to be considered:
  - **Release of more energy-efficient models**: if a *significantly* more energy-efficient model is released, it is sometimes better for the consumer to immediately upgrade
  - **Over-engineering durability**: while some products can be used longer without any design changes, other products need more resource-intensive materials to make them more durable. If customers do not actually use those products for longer, sustainability outcomes can actually be negative
  - **Rebound effects**: There are many types of rebound, but one example relates to the money consumers save from more energy- or material-efficient products (or when buying a product secondhand): they may take their savings and spend it on another product/service with equal or greater negative sustainability impact
- Planetary boundaries imply we must not just reduce our environmental impacts, but ensure we don't cross the irreversible "cliffs" of system boundaries
- **While product longevity is a promising strategy, the increasing evidence of rebound shows us that we need to take even greater responsibility to help ensure our sustainability efforts do not in reality make the situation worse**

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

Thank you

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

References (1 of 4)

[1] Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., Vries, W. de, Wit, C. A. de, Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), 1259855. https://doi.org/10.1126/science.1259855

[2] Bocken, N. M. P., Pauw, I. de, Bakker, C., & Grinten, B. van der. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

[3] den Hollander, M. C., Bakker, C. A., & Hultink, E. J. (2017). Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. *Journal of Industrial Ecology,* 21(3), 517–525. https://doi.org/10.1111/jiec.12610

[4] Iraldo, F., Facheris, C., & Nucci, B. (2017). Is product durability better for environment and for economic efficiency? A comparative assessment applying LCA and LCC to two energy-intensive products. *Journal of Cleaner Production*, 140, 1353–1364. https://doi.org/10.1016/j.jclepro.2016.10.017

[5] Cooper, T. (1994). Beyond recycling: The longer life option. The New Economics Foundation https://irep.ntu.ac.uk/id/eprint/24666/1/201125_7266%20Cooper%20Publisher.pdf

[6] Williams, E. D., & Sasaki, Y. (2003). Energy analysis of end-of-life options for personal computers: Resell, upgrade, recycle. *IEEE International Symposium on Electronics and the Environment*., 187–192. https://doi.org/10.1109/ISEE.2003.1208072

[7] Cooper, T. (2002). Durable consumption: Reflections on product life cycles and the throwaway society. *Proc. of Lifecycle Approaches to Sustainable Consumption Workshop*, 11–27.

[8] van Loon, P., Diener, D., & Harris, S. (2021). Circular products and business models and environmental impact reductions: Current knowledge and knowledge gaps. *Journal of Cleaner Production*, 288, 125627. https://doi.org/10.1016/j.jclepro.2020.125627

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

References (2 of 4)

[9] Proske, M. (2022). How to address obsolescence in LCA studies – Perspectives on product use-time for a smartphone case study. *Journal of Cleaner Production*, 376, 134283. https://doi.org/10.1016/j.jclepro.2022.134283

[10] Richter, J. L., Tähkämö, L., & Dalhammar, C. (2019). Trade-offs with longer lifetimes? The case of LED lamps considering product development and energy contexts. Journal of Cleaner Production, 226, 195–209. https://doi.org/10.1016/j.jclepro.2019.03.331

[11] Nishijima, D. (2016). Product lifetime, energy efficiency and climate change: A case study of air conditioners in Japan. *Journal of Environmental Management,* 181, 582–589. https://doi.org/10.1016/j.jenvman.2016.07.010

[12] Hektoen, M. (2016). Modelling the environmental benefit of a lifetime extension on a laptop to facilitate pro-environmental behaviour [Master thesis, NTNU]. In 44. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/2401244

[13] Lu, B., Li, B., Song, X., & Yang, J. (2021). Multi life cycle assessment: A potential assessment method for product lifespan and environmental performance. *Product Lifetimes and the Environment (PLATE), Virtual Conference*. https://doi.org/10.31880/10344/10255

[14] Bakker, C., Wang, F., Huisman, J., & den Hollander, M. (2014). Products that go round: Exploring product life extension through design. *Journal of Cleaner Production*, 69, 10–16. https://doi.org/10.1016/j.jclepro.2014.01.028

[16] Magnier, L., & Mugge, R. (2022). Replaced too soon? An exploration of Western European consumers' replacement of electronic products. *Resources, Conservation and Recycling*, 185, 106448. https://doi.org/10.1016/j.resconrec.2022.106448

[17] Ardente, F., & Mathieux, F. (2014). Environmental assessment of the durability of energy-using products: Method and application. *Journal of Cleaner Production*, 74, 62–73. https://doi.org/10.1016/j.jclepro.2014.03.04

[18] Pangburn, M., & Stavrulaki, E. (2014). Take back costs and product durability. *European Journal of Operational Research*, 238(1), 175–184. https://doi.org/10.1016/j.ejor.2014.03.008

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

References (3 of 4)

[19] Bernard, S. (2019). Multidimensional Green Product Design. *Environmental and Resource Economics*, 72(4), 1183–1202. https://doi.org/10.1007/s10640-018-0243-y

[20] Bobba, S. (2019). Lifetime extension of products as Circular Economy strategy. Applications in key sectors for the EU. *Politecnico di Torino.* https://core.ac.uk/download/pdf/270202111.pdf

[21] Bakker, C. A., & Schuit, C. S. C. (2017). The Long View: Exploring Product Lifetime Extension. *UN Environment*. https://research.tudelft.nl/en/publications/the-long-view-exploring-product-lifetime-extension

[22] Castro, C. G., Trevisan, A. H., Pigosso, D. C. A., & Mascarenhas, J. (2022). The rebound effect of circular economy: Definitions, mechanisms and a research agenda. *Journal of Cleaner Production*, 345, 131136. https://doi.org/10.1016/j.jclepro.2022.131136

[23] Makov, T., & Font Vivanco, D. (2018). Does the Circular Economy Grow the Pie? The Case of Rebound Effects From Smartphone Reuse. *Frontiers in Energy Research*, 6. https://doi.org/10.3389/fenrg.2018.00039

[24] André, H., & Björklund, A. (2023). A framework to open the black box of the use phase in circular economy life cycle assessments: The case of shell jacket reuse. *Journal of Industrial Ecology*, 27(4), 1137–1150. https://doi.org/10.1111/jiec.13408

[25] Niero, M., Jensen, C. L., Fratini, C. F., Dorland, J., Jørgensen, M. S., & Georg, S. (2021). Is life cycle assessment enough to address unintended side effects from Circular Economy initiatives? *Journal of Industrial Ecology*, 25(5), 1111–1120. https://doi.org/10.1111/jiec.13134

[26] Font Vivanco, D., & van der Voet, E. (2014). The rebound effect through industrial ecology's eyes: A review of LCA-based studies. *The International Journal of Life Cycle Assessment*, 19(12), 1933–1947. https://doi.org/10.1007/s11367-014-0802-6

[27] Font Vivanco, D., Freire-González, J., Galvin, R., Santarius, T., Walnum, H. J., Makov, T., & Sala, S. (2022). Rebound effect and sustainability science: A review. *Journal of Industrial Ecology*, 26(4), 1543–1563. https://doi.org/10.1111/jiec.13295

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0

References (4 of 4)

[28] Lowe, B. H., Bimpizas-Pinis, M., Zerbino, P., & Genovese, A. (2024). Methods to estimate the circular economy rebound effect: A review. *Journal of Cleaner Production*, 443, 141063. https://doi.org/10.1016/j.jclepro.2024.141063

[29] Zink, T., & Geyer, R. (2017). Circular Economy Rebound. *Journal of Industrial Ecology*, 21(3), 593–602. https://doi.org/10.1111/jiec.12545

[30] Maier, J., Geyer, R., & Steigerwald, D. G. (2023). Curbside recycling increases household consumption. *Resources, Conservation and Recycling,* 199, 107271. https://doi.org/10.1016/j.resconrec.2023.107271

Product Longevity: An Academic Literature Review © 2024 by More Than Sustainability is licensed under CC BY-SA 4.0