

A Methodology for Correlating Annualized Replacement Rate (ARR) Reduction to Sustainability Benefits

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Reducing the Annualized Replacement Rate (ARR) of a product brings a two-fold benefit to its sustainability impact. Firstly, it reduces the warranty stockpile and therefore a lower carbon footprint required to fulfill warranty replacements. Secondly, it extends the lifetime of the product, which reduces the overall carbon footprint every year during use. This paper discusses a methodology to quantify the amount of carbon emission (kgCO₂e) that is mitigated when the ARR of a consumer product is reduced because of durability improvements. This methodology is generalizable and can be applied to all consumer products in any product category.

Keywords: Annualized Replacement Rate (ARR), carbon footprint, sustainability, product reliability, circularity, consumer product

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) issued its most dire report yet on the consequences of inaction in regards to mitigating carbon emissions [1]. Companies have been stepping up globally to take action, with many committing to achieving net-zero targets in alignment, or even faster, than the latest climate science. These net-zero targets often include reducing the carbon footprint of the products that a company designs and manufactures, which are usually considered as part of product-based company's Scope 3 carbon emissions according to the Greenhouse Gas Protocol [2].

There are several strategies to help reduce the carbon footprint of a product along its life cycle, including but not limited to:

- (i) Reducing materials used in the product
- (ii) Using recycled or low-carbon materials
- (iii) Minimizing transportation distance
- (iv) Improving energy efficiency
- (v) Extending a product's usable life

In this study, we focus on quantifying how reducing the Annualized Replacement Rate (ARR) of a product mitigates its carbon footprint.

2. Annualized Replacement Rate (ARR)

The Annualized Replacement Rate (ARR) of a product refers to the percentage of customer products, annualized over the products' lifetime,

that has become defective during customer use and subsequently replaced by the manufacturer. ARR is projected based on actual field replacement data. To calculate the ARR improvement, we perform experiments to simulate the potential failure modes on products with expected design improvements and compare them with the baseline design. The ARR improvement can then be calculated using stress-strength analysis by comparing the difference in failure probabilities of the improved and baseline designs.

3. Correlating ARR to Sustainability Benefits

A reduction in ARR of a product corresponds to two carbon footprint benefits: 1) Warranty Stockpile Prevention, and 2) Product Lifetime Extension.

First, Reducing ARR eliminates the carbon footprint associated with the replacement units that are no longer needed to be manufactured and stockpiled. The formula for calculating the carbon footprint reduction of a product based on warranty prevention is:

$$\Delta CF = \Delta ARR \times W \times CF \quad (1)$$

where ΔCF is the expected carbon footprint reduction in kgCO₂e/use-year/unit, ΔARR is the expected ARR reduction (annualized to 12 months), W is the warranty period (in years) and

CF is the carbon footprint of the baseline (prior-generation) product in $\text{kgCO}_2\text{e/use-year/unit}$.

Second, increasing a product's lifetime can reduce the carbon footprint per use-year since the overall footprint is now spread over a longer usable life in the field. For an electronic device, using a more durable display glass, increasing RAM for better customer experience (CX), or allowing the battery to be removed for increased refurbishment could theoretically lead to longer product lifetime.

One way to measure the useful lifetime of a product is to measure the activity of the devices sold. Consider the Monthly Active Device (MAD) profile of a hypothetical product as shown in Fig. 1 below.

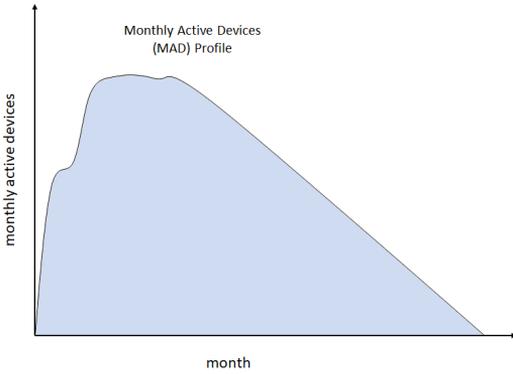


Fig. 1. Monthly Active Device (MAD) profile of a hypothetical product. Y-axis denotes the total number of monthly active devices being used.

The average use-year of a product, (L_{avg}), can be calculated by dividing the total area under the MAD profile by the total volume of devices (V) sold over the lifetime of the product. N denotes the number of months where the device is active:

$$L_{avg} = \frac{1}{12} \frac{\sum_{i=1}^N MAD_i}{V} \quad (2)$$

Reducing ARR contributes to the extension of the MAD profile if we compare different generations of products. A reduction in ARR due to improved durability and/or reliability of the product translates to an increase in overall product utilization as more undamaged devices can now remain in service. We can now apply the monthly

ARR reduction benefit ($\Delta ARR/12$) to MAD_i to calculate the increased lifetime of the product, L_{avg_ARR} :

$$L_{avg_ARR} = \frac{1}{12} \frac{\sum_{i=1}^N MAD_i (1 + \Delta ARR_i)}{V} \quad (3)$$

To incorporate device lifetime extension into the product's carbon footprint, we introduce a new metric: **carbon/use-year**, which is the amount of carbon emitted per year of device lifetime. Under this framework, durability improvements lead to a longer product lifetime (L_{avg_ARR}), which then generally results in the reduction of the product's carbon footprint per use-year.

4. Conclusion

Reducing the ARR of a product can contribute to reducing the carbon footprint of Scope 3 emissions through warranty stockpile prevention and by extending a product's lifetime. A new methodology is presented in this study to quantify the estimated amount of carbon reduction due to ARR improvements. This method is applicable to all consumer products where data is available. By developing a quantifiable way to estimate the carbon reduction of product durability and reliability improvements, we provide a means to justify and drive investment towards durability innovations during product design.

Acknowledgement

We thank our colleagues from Amazon Lab126 for offering their expertise and time for relevant discussions.

References

- [1] Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. <https://www.ipcc.ch/report/ar6/wg2/>
- [2] Hertwich, Edgar G., and Richard Wood (2018). "The growing importance of scope 3 greenhouse gas emissions from industry." Environmental Research Letters 13, no. 10.