Optimizing Embodied Emissions

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In a recent column, I wrote about understanding embodied emissions in terms of how they are measured and accounted for based on the Greenhouse Gas Protocol (GHG) [1]. In this column, I will discuss how embodied emissions can be optimized and research challenges that our community can address. First, a quick recap. Embodied emissions, also known as scope 3 emissions, are indirect emissions of an organization that result from all other upstream and downstream activities, such as from purchased goods and services [2]. Operational emissions, on the other hand, are emissions resulting from burning fuels or consuming energy such as electricity. To decarbonize any system, it is important to reduce both its embodied and operation emissions, collectively referred to as lifecycle emissions.

In recent years, there has been a lot of interest in optimizing operational emissions (also known as operational carbon) of systems such as cloud platforms or the electric grid. For example, this can be achieved for cloud workloads by shifting work to times of the day when more low-carbon energy becomes available or by moving work to regions with plenty of green energy. While these types of techniques have received increasing attention recently, there has been much less research on reducing embodied emissions using computing methods.

The relative proportions of embodied and operational carbon in any system can vary significantly. In consumer electronics goods such as smartphones and computing products such as personal computers, embodied emissions dominate and can constitute as much as 80% of the total lifecycle emissions of the product, which means that operational emissions generate only 20% of the total emissions attributed to that product over its lifetime. In contrast, for buildings, which have lifetimes of many decades, operational emissions dominate and can constitute 70-80% of the total emissions, with embodied emissions comprising the rest. This is due to the long lifetimes of a building, which causes the energy consumed by the building over this long timespan to become the dominant cause of carbon emissions relative to the embodied emissions contained in the materials used to construct the building. Regardless of the relative proportions, optimizing embodied emissions is an important problem and requires different techniques from those used to optimize operational carbon.

Optimizing embodied emissions requires attention at three stages – manufacturing of the item, purchase or installation of the item, and over the operational life of the item. First, the manufacturer of an item as well as the supply chain that provided raw materials or components for its manufacture can themselves reduce their carbon emissions by adopting green manufacturing practices. In doing so, they can reduce the emissions embodied in each item they manufacture. However, this is a challenging problem since supply chains for many items are quite complex, making them difficult to decarbonize, and the manufacture of items such as semiconductors is very energy-intensive and, consequently, also carbon-intensive. In many cases, the location of the factory that produces an item can also dictate its embodied emissions by virtue of whether the local electric grid supplies green (or brown) electricity. Depending on the location, the transport of the item can increase the overall scope 3 emissions. As such, local production, when feasible, becomes crucial for minimizing transport-related embodied emissions. Recently, semiconductor manufacturers have announced plans to reduce their carbon footprint in the coming decades, which, if realized, can significantly decarbonize the downstream computing industry.

A second approach is for the consumer of an item to make a green choice by purchasing a greener product when such choices are available. For example, a user who wishes to purchase a new television (or a smartphone) can also consider the embodied emissions of the various models and choose the one with lower embodied carbon. However, making such decisions is never straightforward since alternative models may have somewhat different features, functionality, and cost. Hence, such decisions may require complex tradeoffs in terms of choosing a product that has lower emissions while also providing the desired functionality at an acceptable cost. Optimizing embodied emissions has emerged as an important focus within the computing architecture community that is studying techniques for making such tradeoffs during hardware design. Other communities can learn from these efforts and tailor them for other domains.

A final approach is to optimize embodied carbon by increasing the lifetime of a product (e.g., by using it for a longer duration before it is replaced, recycled, or discarded). In doing so, the embodied emissions from manufacturing the item get amortized over a longer lifespan. However, increasing the lifetime of any product raises its own set of challenges. As a product (e.g., a car or a computer) gets older, it is more prone to failures, which increases maintenance costs. The product also becomes less energy efficient than a more recent generation of the product. For example, an older car will be less fuel efficient than a newer model and will also incur higher repair costs. Within computing systems, these problems can be addressed by designing new techniques to mask the lower reliability of older computers or to reduce energy waste when running less efficient equipment. Similar ideas can be applied to other domains as well. Overall, there is rich design space for optimizing embodied carbon that can benefit from new research on this emerging topic!

References

[1] P. Shenoy and D. Irwin, Understanding Embodied Emissions, ACM Energy Informatics Review, Sept 2023.

[2] Greenhouse Gas Protocol, Scope 3 Frequently Asked Questions. Online at `https://ghgprotocol.org/sites/default/files/2022-12/Scope%203%20Detailed%20FAQ.pdf`

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