The War of the Efficiencies: Understanding the Tension between Carbon and Energy Optimization

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ABSTRACT

Major innovations in computing have been driven by scaling up computing infrastructure, while aggressively optimizing operating costs. The result is a network of worldwide datacenters that consume a large amount of energy, mostly in an energy-efficient manner. Since the electric grid powering these datacenters provided a simple and opaque abstraction of an unlimited and reliable power supply, the computing industry remained largely oblivious to the carbon intensity of the electricity it uses. Much like the rest of the society, it generally treated the carbon intensity of the electricity as constant, which was mostly true for a fossil fuel-driven grid. As a result, the cost-driven objective of increasing energy-efficiency — by doing more work per unit of energy — has generally been viewed as the most carbon-efficient approach. However, as the electric grid is increasingly powered by clean energy and is exposing its time-varying carbon intensity, the most energy-efficient operation is no longer necessarily the most carbon-efficient operation. There has been a recent focus on exploiting the flexibility of computing's workloads—along temporal, spatial, and resource dimensions—to reduce carbon emissions, which comes at the cost of either performance or energy efficiency. In this paper, we discuss the trade-offs between energy efficiency and carbon efficiency in exploiting computing's flexibility and show that blindly optimizing for energy efficiency is not always the right approach.

CCS CONCEPTS

• **Computer systems organization** → **Cloud computing**; • **Hardware** → **Renewable energy**; • **Social and professional topics** → **Sustainability**.

KEYWORDS

Carbon Efficiency, Energy Efficiency, Sustainable Computing

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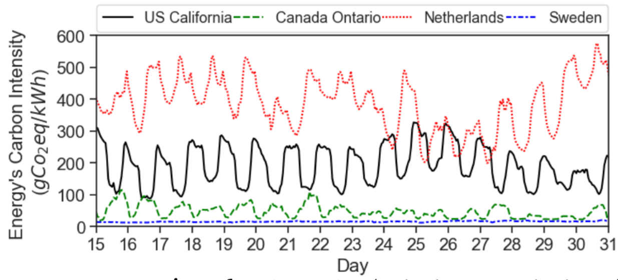

Figure 1: ***Energy's carbon intensity (05/15/2022 - 05/31/2022).***

1 INTRODUCTION

The demand for computing has experienced rapid growth and is expected to accelerate even further. However, the increase in computing demand has not resulted in a proportional increase in energy demand so far [3]. The growth in computing's energy consumption has been kept in check by massive gains in algorithmic efficiency, measured in cycles per unit of work, of its software and energy efficiency, measured in energy consumption per cycle, of its hardware [13]. However, as the algorithmic and energy efficiency gains slow down, an increase in computing demand directly increases the energy demand. A conservative estimate projects that the energy consumption of datacenters will increase by at least 10% per year till 2030 [11], much higher than an estimated increase of 1.65% per year in 2010s [24]. As society has begun to recognize the environmental impact of our activities, reducing the carbon footprint of this accelerating energy demand has attracted significant attention from academic researchers [21, 31, 33, 35] and industry leaders [9, 28].

The carbon footprint of computing depends on the computing's carbon efficiency, denoted as η_C, which is calculated by dividing the computing's energy efficiency η_E, measured as work done per unit of energy, by the energy's carbon intensity c, measured as the amount of emitted greenhouse gases (GHG) per kWh of energy. Traditionally, the electric grid has been powered by fossil fuels such as coal, and oil, which have similar carbon intensities of 1038 $g.CO_2eq/kWh$ and 1106 $g.CO_2eq/kWh$ [2]. Furthermore, even if energy's carbon intensity slightly varied across space and time, it was invisible to electricity consumers due to the simple and opaque abstraction exposed by the grid. As a result, the carbon intensity of electricity was viewed as constant, every unit of energy was the same, and a unit improvement in computing's energy efficiency meant a proportional improvement in computing's carbon efficiency. As the industry aggressively optimized for computing's energy efficiency—driven by the need to scale while reducing operational costs—it was only serendipitous that a cost-driven approach was also the environmentally conscious choice.