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The carbon footprint of computational research

Monitoring and reporting on the environmental impact of computational science research is critical to ensure a more sustainable future.

The world is on the brink of a climate catastrophe, and this is far from an overstatement. According to the latest report on the United Nations Sustainable Development Goals, human activities have caused global warming of 1.1 °C above pre-industrial levels and the world is likely to surpass the critical 1.5 °C tipping point by 2035 if urgent global greenhouse gas (GHG) emission reductions do not take place[1]. More must be immediately done to avoid a damaging increase in global temperatures.

The scientific community has been working to better understand and address its own impact on the environment and global warming[2]. The average carbon footprint of scientists, for instance, is estimated to be greater than the carbon budget per person to keep global warming below 1.5 °C (ref. 3). In particular, computational science research, while playing a critical role in finding solutions for environmental and sustainability problems — as recently highlighted in our Focus issue — can also take a heavy toll on the environment. For instance, in 2020, the sector of information and communication technologies was responsible for between 1.8% and 2.8% of GHG emissions, surprisingly more than the sector of aviation[4]. The use of high-performance computing (HPC) systems makes a substantial impact on the environment as well. HPC hardware often involves complex industrial processes and depends on costly resources, and it goes without saying that HPC use requires a large amount of energy. It is also worth noting that artificial intelligence, while undoubtedly responsible for many breakthroughs in science, is itself a significant emitter of carbon[5], including large language models[6]. Finally, obsolete hardware — which eventually becomes electronic waste (or e-waste) — is usually moved to low- and middle-income countries, where it can cause deleterious environmental and health effects in these regions[7,8].

A challenge in environmentally sustainable computational research is how to quantify the impact of software and algorithms on the environment, which is sometimes underestimated. Having said that, more attention has been recently given to this issue in different computational communities[3,9,10] and initiatives such as the Green Software Foundation have been implemented to make sustainability a core priority in software development.

The main source of the GHG emissions in computational science is the power draw of computers during compute- and data-intensive computational analyses, and to estimate this energy consumption, the usual approach is to focus on the power draw of processing cores — such as central processing units (CPUs) and graphics processing units (GPUs) — and the quantity of memory available. Based on these concepts, many tools and calculators have recently become available to track carbon emissions — most of them targeted at machine learning tasks. For instance, Web resources such as Green Algorithms[11] and Machine Learning Emissions Calculator[12] can be used by researchers to estimate the carbon footprint of their research by manually providing details of the algorithm execution. Other tools — such as CarbonTracker[13], CodeCarbon and Cumulator — can be directly integrated into the code for automatically tracking the GHG emissions. Finally, resources such as GreenAlgorithms4HPC, Cloud Carbon Footprint, and Tracarbon can be used when an HPC or cloud system is being employed in the research.

Certainly, estimating the carbon footprint is only one aspect of environmentally sustainable computational science. Loïc Lannelongue and colleagues recently laid out different axes of the problem that need to be addressed[4], including issues related to governance, responsibility, and cultural change. In addition, the aforementioned challenges related to the cost of hardware production and the consequences of e-waste cannot be ignored.

Nevertheless, reporting the carbon footprint of computational research is a start, which will hopefully motivate computational scientists to think more critically about how to design energy-efficient software and algorithms. We strongly encourage our authors to estimate the impact of their research to the best of their abilities, and to report the results in their manuscripts. These may seem like small steps to researchers, but they represent a big step towards building a more sustainable world.

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