Fachbereich Medien
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Master Thesis

Study on Proof-of-Concept for Resource-Optimised AI Benchmarking: Efficiency, Cost, and Sustainability in Small-Medium Enterprises (SMEs)

submitted in fulfilment of the requirements for the degree of
Master of Science

written by
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Study on Proof-of-Concept for Resource-Optimised AI Benchmarking: Efficiency, Cost, and Sustainability in Small-Medium Enterprises (SMEs)

Heansuh Lee

Abstract

While Artificial Intelligence (AI)'s capabilities are becoming more powerful than ever, they demand substantial computational resources, raising critical concerns about cost, scalability, and environmental impact, which is already becoming a significant issue, for example with the data centres and Graphics Processing Unit (GPU) clusters. This brings challenges for small and medium-sized enterprises (SMEs), which often lack the infrastructure and capital of their larger counterparts, hindering their ability to adopt AI efficiently. This thesis aims to cover this gap by proposing a Proof-of-Concept (PoC) benchmarking framework designed to assess AI efficiency across four key dimensions: accuracy, runtime, cost, and energy consumption. The framework is developed through a comprehensive literature review of existing benchmarking tools and a critical evaluation of modern AI hardware architectures, including GPUs, specialised accelerators, and emerging data centre infrastructures. As a practical implementation, this research introduces Project HANSAL (Hybrid AI for Next-gen: Sustainable, Affordable, and Lightweight). This concept is applied to the framework to provide SMEs with insights for their domain-specific business cases by measuring their AI systems that strategically balance high performance with resource sustainability. Providing a structured framework and reference guide for resource optimisation in AI, this thesis aims to offer both academic and industrial values by supporting energy-aware, cost-efficient AI adoption. While it focuses on its applicability for SMEs, it touches on the possibility for larger corporations to adopt this concept and framework, based on their business needs and counterparts.

Declaration

I, Heansuh Lee, declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given in the bibliography.

City, Date

Heansuh Lee

Acknowledgements

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1 Introduction

Artificial intelligence (AI) systems have advanced rapidly over the past decade, driven in particular by deep learning models with growing parameter counts and training data scales. These advances have led to substantial increases in computational demand, which translate directly into higher electricity consumption and associated carbon emissions from data centres and specialised hardware such as GPU clusters. Recent analyses show that training and operating modern AI models can consume megawatt-hours (MWh) of energy and contribute non-negligibly to the overall climate impact of information and communication technologies.

1.1 Motivation

AI systems, particularly modern deep learning models, require large volumes of computation for both training and inference, which directly translates into substantial electricity consumption and hardware demand. Studies show that training and operating contemporary deep learning models can consume MWh of energy, with runtime energy use scaling strongly with model size, data volume, and chosen hardware. As these workloads migrate from individual servers to large GPU clusters, their aggregate impact becomes significant within the overall information and communication technology (ICT) sector, which already accounts for several percent of global electricity use and around 1–2% of global greenhouse gas emissions.

A growing share of this footprint is concentrated in data centres, whose electricity demand in Europe has been rising steadily and is expected to continue increasing with the expansion of AI and cloud services. Recent scenario analyses project that data-centre energy use and associated emissions could roughly double over the coming decade, driven in part by specialised AI infrastructure and dense GPU farms required for training and serving large models. These trends create tension with climate-policy targets, as uncontrolled growth in AI-related energy demand risks undermining broader decarbonisation efforts in the power sector.

In response, the European Union and its member states have articulated explicit goals to make data centres more energy and resource-efficient, including the objective of climate-neutral data centres by 2030 and planned regulatory packages focused on data-centre energy efficiency. Policy analyses around the European Green Deal and the AI Act highlight that energy and resource efficiency should become a core design objective for AI systems, not an afterthought, if AI is to support rather than hinder the energy transition. Against this backdrop, "green AI" and resource-aware AI operation—where energy use, cost, and emissions are treated as metrics alongside accuracy and latency—are increasingly important, especially for organisations that lack the capacity to absorb uncontrolled increases in computational demand.

1.2 Context

Small and medium-sized enterprises (SMEs) typically operate under tighter financial and organisational constraints than large technology companies, which limits their access to specialised AI infrastructure such as dedicated GPU servers, high-performance storage, and professional MLOps teams. Instead, many SMEs rely on a small number of on-premise machines, shared virtual private servers, or pay-as-you-go cloud instances, making it difficult to experiment broadly with different hardware configurations or large-scale models without incurring prohibitive costs.

At the same time, SMEs increasingly view AI as a key lever for maintaining competitiveness, for example through predictive maintenance, demand forecasting, or customer analytics, and thus face pressure to integrate AI into their products and processes. However, they often lack practical guidance on how different combinations of models, frameworks, hardware, and cloud offerings translate into concrete trade-offs between accuracy, runtime, energy use, and monetary cost for their own workloads. This uncertainty can result in suboptimal choices—either overprovisioning expensive infrastructure or underinvesting in AI capabilities—and creates a barrier to energy-aware, cost-efficient adoption of AI in the SME context.

1.3 Problem Statement

Many established AI benchmarks and leaderboards concentrate primarily on model accuracy, and in some cases latency, while assuming access to substantial computational resources such as multi-GPU servers or large cloud clusters. These benchmarks provide valuable insights for model comparison at scale, but they rarely expose energy consumption, monetary cost, or carbon footprint in a form that smaller organisations with limited hardware and budgets can readily apply to their own environments. As a result, SMEs have little empirical support for deciding whether a given model, framework, or deployment option offers an acceptable balance between performance and resource usage on realistic, resource-constrained setups.

In parallel, several specialised tools have emerged that enable more detailed measurement of AI energy use and emissions, including CodeCarbon for estimating carbon footprint from power and grid-intensity data, as well as Zeus and Perun for fine-grained, hardware-level energy profiling of deep learning and high-performance computing workloads. While powerful, these tools are often presented as independent projects or research prototypes, and there is currently no unified, SME-oriented benchmarking framework that integrates them into a coherent workflow which jointly reports accuracy, runtime, cost, and energy consumption for typical AI workloads. This gap makes it difficult for SMEs to systematically compare alternative AI configurations and to incorporate energy- and cost-awareness into everyday model and infrastructure decisions.

1.4 Research Objectives

This thesis develops and evaluates a Proof-of-Concept (PoC) benchmarking framework, Project HANSAL, that enables systematic assessment of AI workloads along four key dimensions: accuracy, runtime, cost, and energy consumption on realistically constrained hardware. The goal is to provide SMEs with a practical, reproducible basis for making informed decisions about AI models, infrastructure, and deployment options under resource and budget limitations.

The research is guided with the following questions:

1. How can SMEs systematically compare AI workloads across accuracy, runtime, cost, and energy consumption using a unified benchmarking framework?
2. To what extent do existing measurement tools such as CodeCarbon, Zeus, and Perun support reliable and interpretable comparisons of AI workloads on modest, SME-typical hardware and infrastructure?
3. What trade-offs between model performance and resource usage emerge in representative workloads when evaluated with this framework, and how can these trade-offs inform energy-aware, cost-efficient AI adoption in SMEs?

2 Background and Literature Review

Motivation and context

2.1 Section

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