Context aware analysis of software energy efficiency at application level

Motivation and Opportunities

SEMTL

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Romain Lefeuvre

University of Rennes
France
romain.lefeuvre@inria.fr

Benoit Combemale

University of Rennes
France
benoit.combemale@irisa.fr

Jessie Galasso

McGill
Canada
jessie.galasso-carbonnel@mcgill.ca

Quentin Perez

INSA
France
quentin.perez@inria.fr

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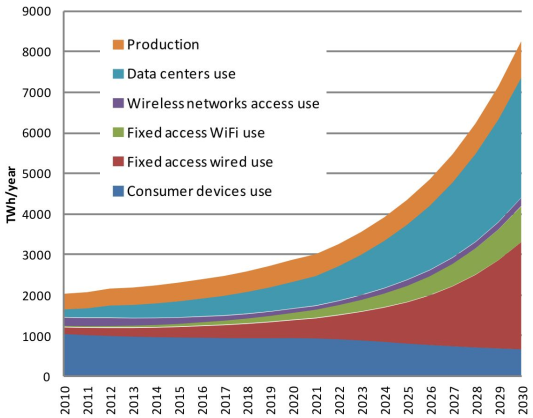
Context : ICT global electricity usage

ICT share on global electricity usage :

- **4%** in **2020** [1]
- might represent **21%** in **2030** [2]
  (study expected scenario)



Trends for ICT "expected-case" global electricity usage 2010–2030.[2]

[1] A. S. G. Andrae and T. Edler, "On Global Electricity Usage of Communication Technology: Trends to 2030," Challenges, vol. 6, no. 1, Art. no. 1, Jun. 2015

[2] J. Malmodin, N. Lövehagen, P. Bergmark, and D. Lundén, "ICT Sector Electricity Consumption and Greenhouse Gas Emissions – 2020 Outcome." Rochester, NY, Apr. 20, 2023. doi: 10.2139/ssrn.4424264.

Energy efficiency: initially considered in terms of hardware and resource scheduling optimization

Global trends in digital and energy indicators, 2015-2022

	2015	2022	Change
Internet users	3 billion	5.3 billion	+78%
Internet traffic	0.6 ZB	4.4 ZB	+600%
Data centre workloads	180 million	800 million	+340%
Data centre energy use (excluding crypto)	200 TWh	240-340 TWh	+20-70%
Crypto mining energy use	4 TWh	100-150 TWh	+2300-3500%
Data transmission network energy use	220 TWh	260-360 TWh	+18-64%

Energy efficiency gain at **hardware** and **system level** partially counterbalance the growth.

[8] Source IEA : https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks

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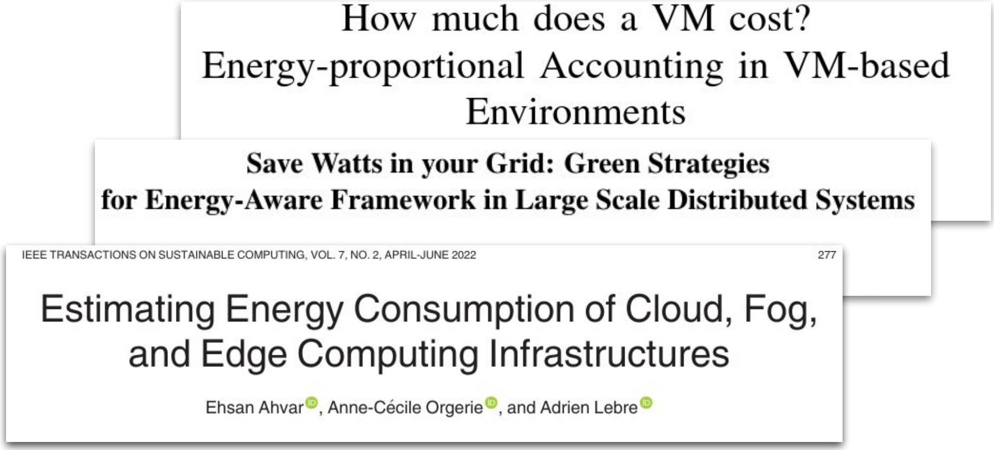


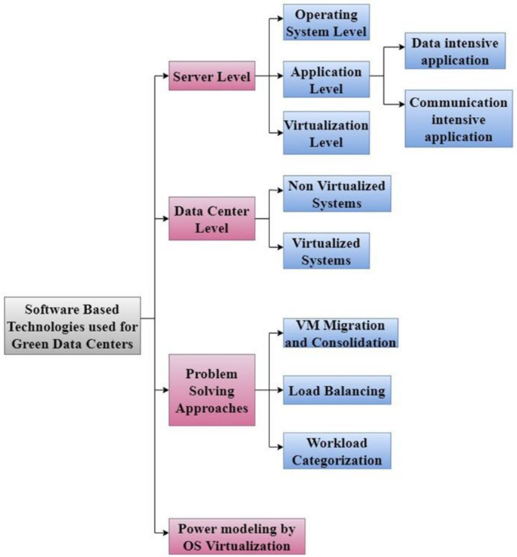
How much does a VM cost?
Energy-proportional Accounting in VM-based Environments

Save Watts in your Grid: Green Strategies for Energy-Aware Framework in Large Scale Distributed Systems

IEEE TRANSACTIONS ON SUSTAINABLE COMPUTING, VOL. 7, NO. 2, APRIL-JUNE 2022 277

Estimating Energy Consumption of Cloud, Fog, and Edge Computing Infrastructures

Ehsan Ahvar, Anne-Cécile Orgerie, and Adrien Lebre



Taxonomy of technique for energy efficiency in cloud computing [9]

Approaches at system level
Application software as black box

Energy efficiency can also be analysed at application software level

[9] A. Katal, S. Dahiya, and T. Choudhury, “Energy efficiency in cloud computing data centers: a survey on software technologies,” Cluster Comput, vol. 26, no. 3, pp. 1845–1875, Jun. 2023, doi: 10.1007/s10586-022-03713-0.

Context aware analysis of **software energy efficiency** at application level

Context aware analysis of software energy efficiency **at application level**

Energy efficiency at software application level

Initially studied for battery powered systems

- Cyber physical system
- Smartphone

A concern rising for SE in general

- Practitioners are willing to address energy issues [13]
- Lack of tools, approach, and methodology to apply [13]
- No global approach that can be applied systematically

[13] Irene Manotas et al. An empirical study of practitioners' perspectives on green software engineering. ICSE '16.

Objective 1 : Characterizing factors of energy consumption at application level

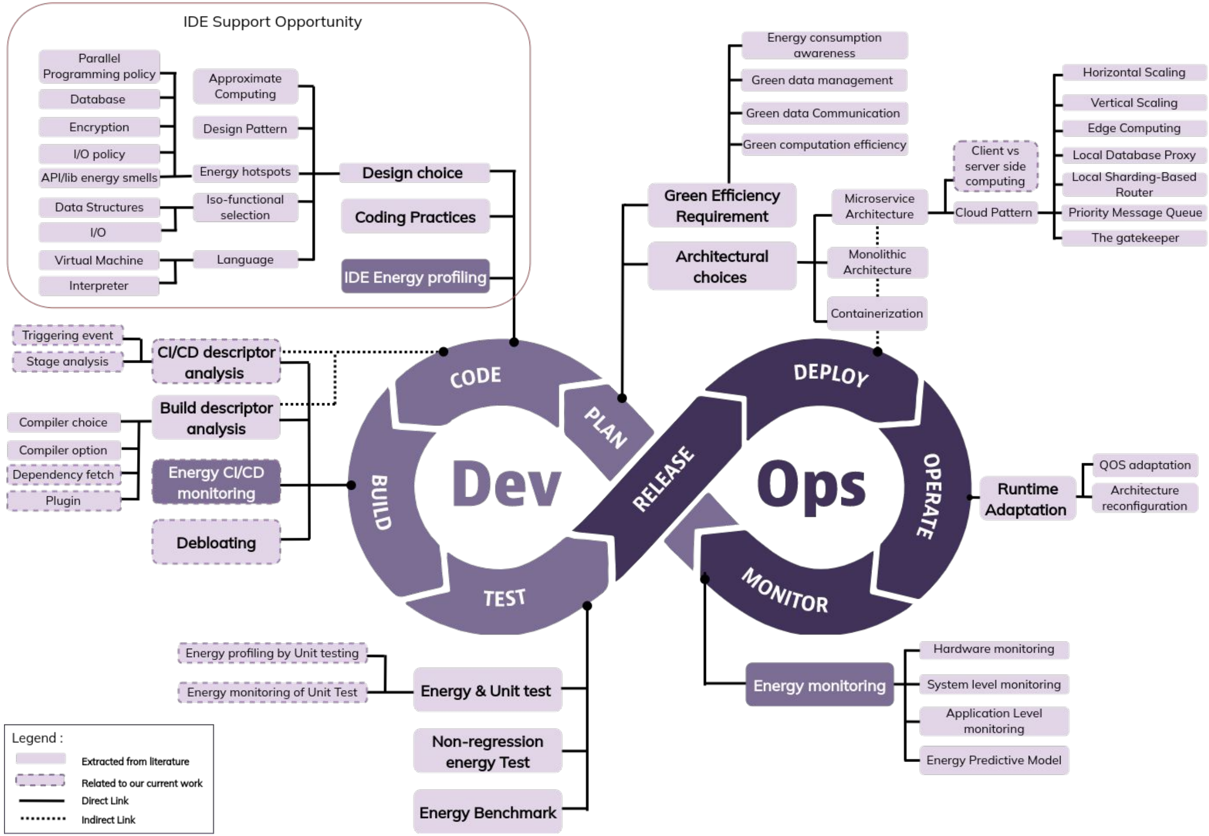
Many studies on specific cases

- Energy aware application
- Energy design pattern
- Impact of java collections implementation
- Impact of configuration on energy consumption
- Impact of software good practices on energy consumption

No recent Systematic Literature Review
No global taxonomy

Objective 1 : Characterizing factors of energy consumption

Mapping energy efficiency studies and concerns to DevOps life cycle [TENTATIVE]



Energy efficiency as a **quality attribute**

That might be **considered on every phase**

Context aware analysis of software energy efficiency at **application level**

Context aware analysis of software energy efficiency at application level

Context capture and Variability point

Energy analysis are highly context dependent

Mode	Cause
Pos	CPU-intensive tasks [29], [30], [31], [32]
	Memory and caching [33], [34]
	Tuning HW params [35], [36], [37]
Neg	CPU-intensive tasks [38], [39]
	Memory and caching [40], [41]
None	Network comm. [42], [24], [43]
	IO-intensive systems [38], [44]
	Tuning CPU&HW params [41], [25]

Overview of the three modes of correlation and the corresponding cause [14]

Correlation between **performance** and **energy consumption**

- **Contradictory result** for same “modeled” context
- Context is not sufficiently captured
- Lots of variability points

[14] M. Weber, C. Kaltenecker, F. Sattler, S. Apel, and N. Siegmund, “Twins or False Friends? A Study on Energy Consumption and Performance of Configurable Software,” in ICSE ’23.

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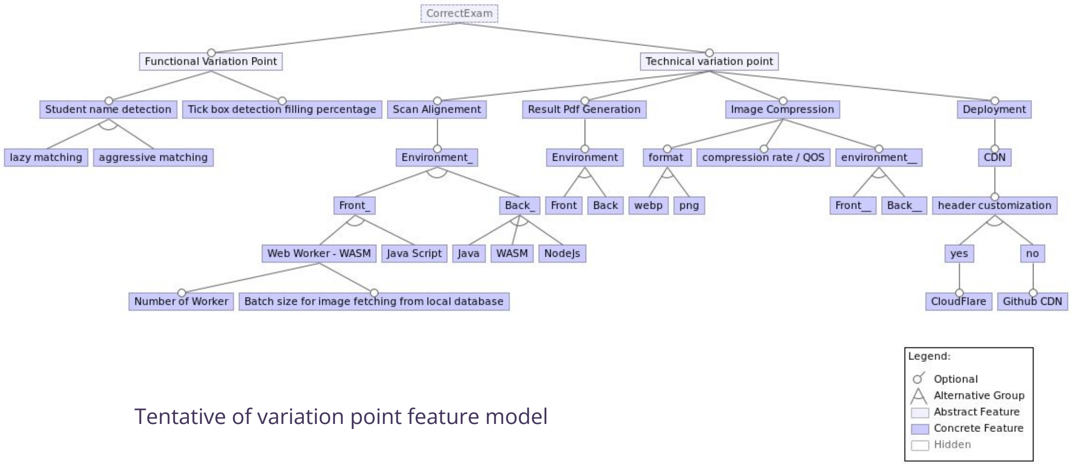
Objective 2 : Context capture and variability points

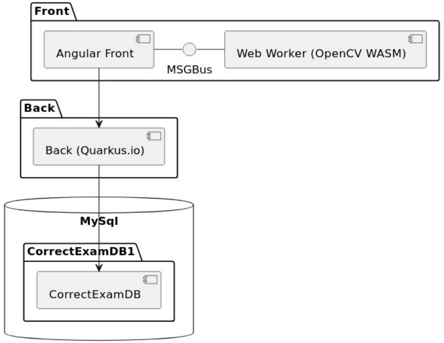
- Identify the variability points in literature studies
- Identify the context and the variability points leading to non-generalization
- How can we describe / formalize the context ?

Objective 2 : Context capture and Variability point

Variability modelling [Tentative]



Tentative of variation point feature model



Correct exam architecture

Create a feature model of correct exam variation point

Measure and evaluate variation point
→ Ex : Server side vs Client side process

Objective 3 : Operationalization

Propose an approach that handles real world software and their context

“The many layers of abstraction in typical applications, combined with subtle interactions between both hardware and software components, suggests **that it is difficult, if not impossible**, for developers to predict how the changes they make will impact the energy consumption of their applications.” Manotas et al. [15]

Energy efficiency approaches needs to be **contextualized**

One approach might be to perform **local optimization** to a **defined context**

[15] I. Manotas, L. Pollock, and J. Clause, “SEEDS: a software engineer’s energy-optimization decision support framework,” in ICSE 2014.

Thanks

Key points :

- **Objective 1 : Characterizing factors** of energy consumption at **application level**
- **Objective 2 : Context** capture and **variability** point identification
- **Objective 3 :** Propose an approach that can be applied to **real world software** and their **context**
- Consider **energy efficiency** as a **quality attribute** handled within software lifecycle

Different scenarios depending on the study : other sector enablement and rebound effect

Assumptions about demand for ICT

Assumptions about efficiency	increases less than or in line with efficiency	increases more than efficiency
continues	'Efficiency saves ICT' Emissions decline or stabilise *e.g. Malmodin, Masanet*	'Jevons Paradox' Emissions increase *e.g. Hilty, Galvin, Magee*
stops	'Jevons stalled' Emissions stabilise	'Growth without efficiency' Emissions increase rapidly *e.g. Andrae, Belkhir*

Rebound effect > 100% = Jevons Paradox

Resource savings are negative because usage increased beyond potential savings

Efficiency is needed to reduce emission

[5] C. Freitag, M. Berners-Lee, K. Widdicks, B. Knowles, G. S. Blair, and A. Friday, "The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations,"