Evaluating the Energy Profile of Tasks Managed by Build Automation Tools in Continuous Integration Workflows:

The Case of Apache Maven and Gradle

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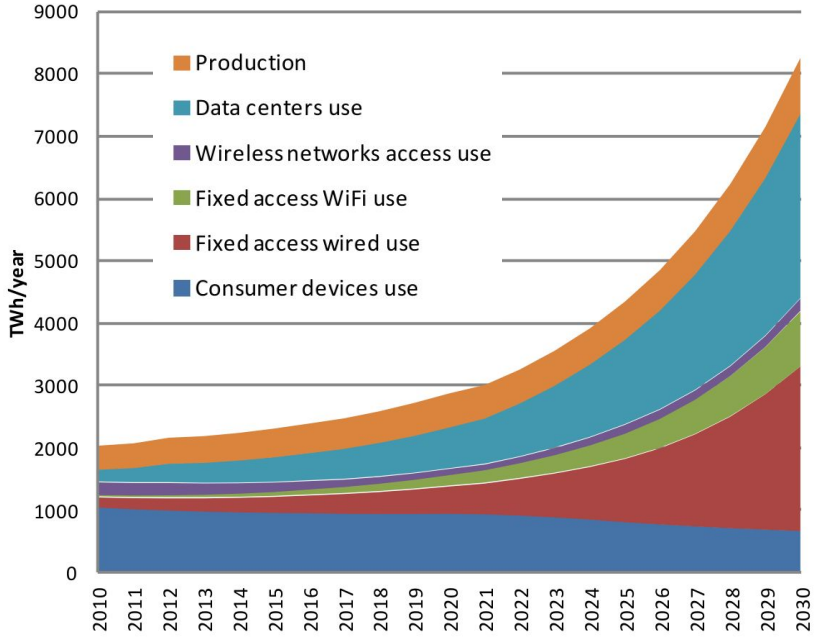
Energy consumption of ICT

ICT share on global electricity usage :

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

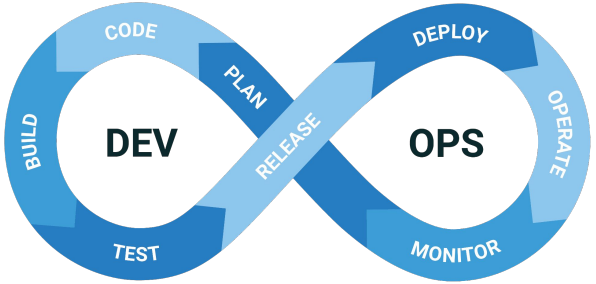


Trends for ICT expected-case global electricity usage 2010–2030.[2]

[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.

Modern software development

- Short iteration
- Iterative and incremental method
- Code integrated into code base on a daily basis



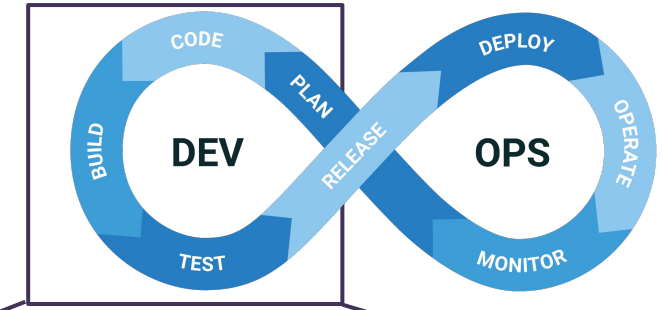
... Through DevOps methodology [1]

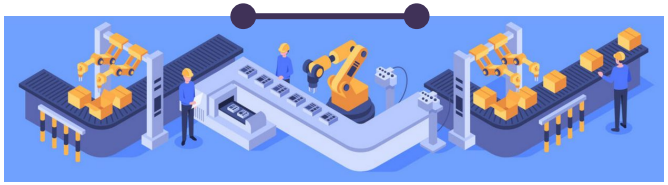
- Two kinds of phases:
  - Development “**Dev**”
  - IT Operations “**Ops**
- Promotes the **automation** and monitoring all along the cycle
- Uses monitoring feedback to improve the upstream phases

[3] Jabbari, Ramtin, et al. "What is DevOps? A systematic mapping study on definitions and practices." Proceedings of the Scientific Workshop Proceedings of XP2016. 2016.

Continuous integration workflows

- **A Continuous Integration Workflow** can be seen as an **assembly line** in a factory.
- A CI workflow is a set of **steps** that automate :
  - The production of an executable software (a product) from source code (raw material) .
  - The integration of code change





Assembly line

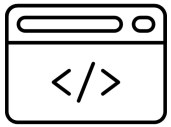
≃

... | compilation | Test | Package | Release | ...

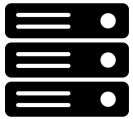
CI Workflow

Rely heavily on build system Maven™ Gradle

Continuous integration in practice



Workflow descriptor



Computing Resource to Execute it

CI workflow

```yaml
name: build
on:
  pull_request:
    branches:
    - main
  push:
    branches:
    - main
...
jobs:
  build:
    runs-on: ubuntu-latest
    steps:
    - name: Checkout
      uses: actions/checkout@v3
      ...
    - name: Set up JDK
      uses: actions/setup-java@v3
      ...
    - name: Compile
      run: ./mvnw clean package -DskipTests
    - name: Test
      run: ./mvnw verify -P "${{ matrix.profile }}" -B
    - if: github.event_name != 'pull_request'
      name: Coverage
      run: ./mvnw -P coverage coveralls:report ...
        }}
    ...
```

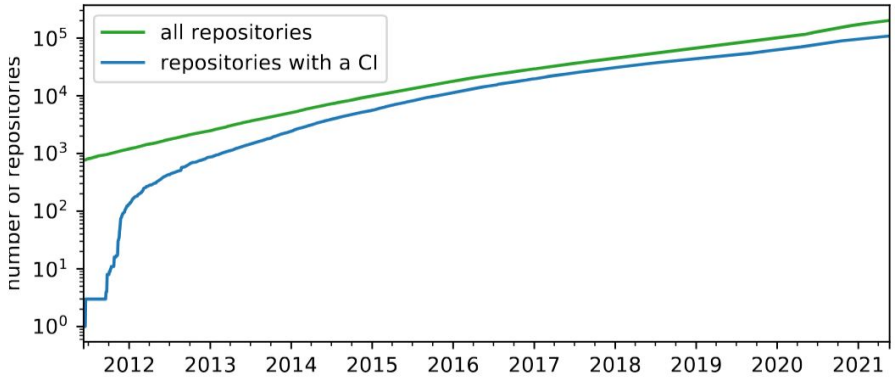
Step

Tool

Example of workflow descriptor

Continuous Integration is accessible within a few clicks

A plenty of tools and platforms offering **cloud resources … intangible for developers**



Evolution of the number of repositories (green line) and number of repositories using a CI (blue line) , from npm[4]

… **4 clicks** to create a Java pipeline

[4] Mehdi Golzadeh, Alexandre Decan, and Tom Mens. On the rise and fall of CI services in github. In 29th IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER), pages 662–672, Honolulu, HI, USA, March 2022. IEEE

Handling the energy consumption associated to continuous integration

- CI is becoming a standard practice
- There is a need to **evaluate its impact** and identify the most energy consuming tasks to focus on
- Only studied from a financial perspective [5]
- CI relies heavily on **build systems**, which developers also use daily
- Java is widely adopted, with Maven and Gradle as the primary build systems.

[5] Islem Bouzenia and Michael Pradel. 2024. Resource Usage and Optimization Opportunities in Workflows of GitHub Actions. In Proceedings of the IEEE/ACM 46th International Conference on Software Engineering (ICSE '24).

Research Questions :

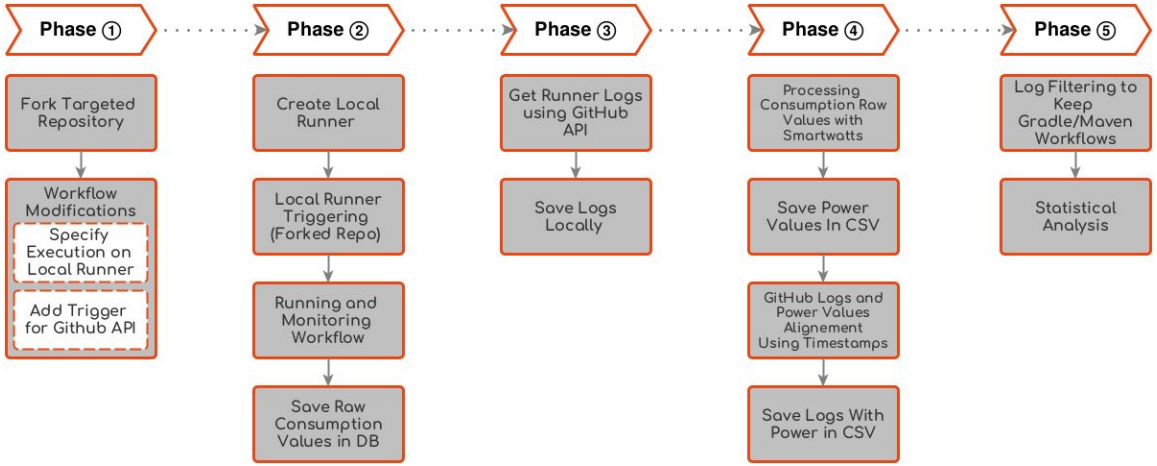
RQ1. How is the overall energy consumption associated with Maven/Gradle tasks?

RQ2. How is the energy consumption profile by category of Maven/Gradle task?

Research Methodology

Large-scale measurement of CI workflow execution energy consumption

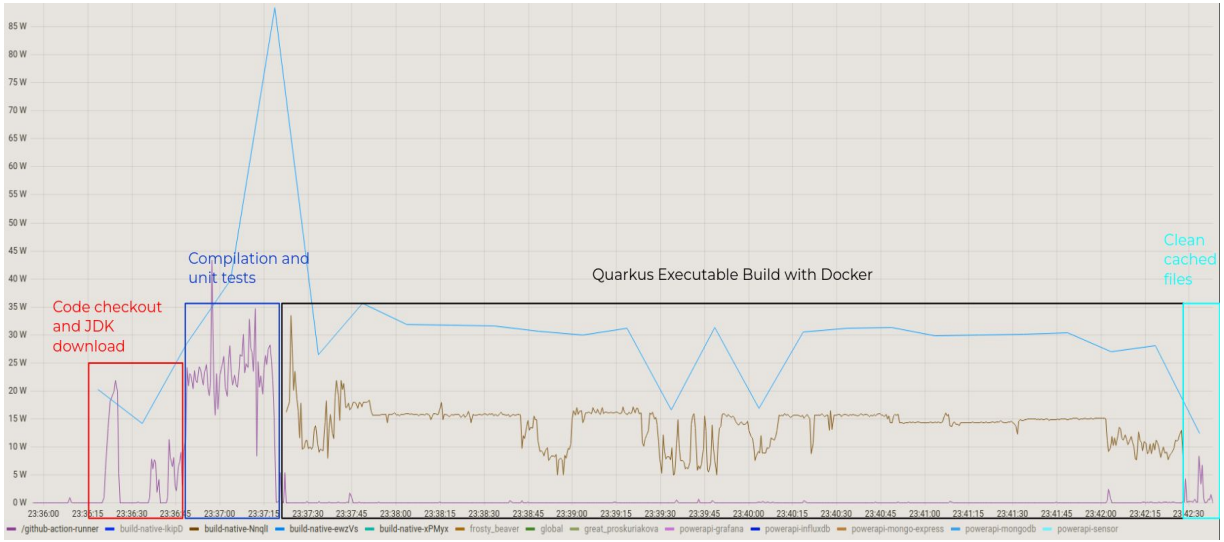
- Project using Java and Maven or Gradle (>100 stars)
- And that declare a github actions



3170 workflows execution associated to **1168** repositories

Measuring Energy consumption

- CPU energy measurement
- Software based measurement
- On a self hosted GitHub Runner



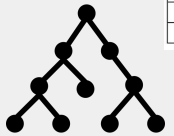
Consumption profile of maven.yml workflow from the CorrectExam project

https://github.com/correctexam/corrigeExamBack/blob/deploy/.github/workflows/maven.yml

Retrieve energy consumption at build system tasks level

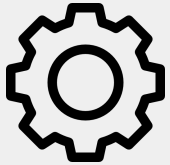
Execution logs

Energy measures



Task parser

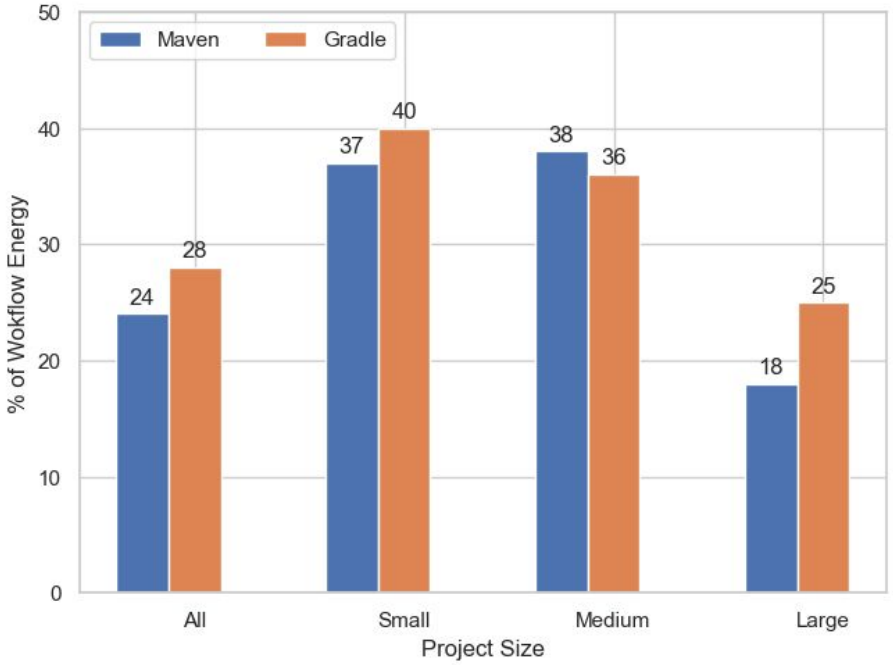
Category
Integration Testing (Int Test)
Unit Testing (Unit Test)
Compile
Documentation (Doc)
Install
Linter
Packaging (Pack)
Others
Unclassified (Unclass)



Data alignement

Classified tasks mapped with energy consumption

Overview



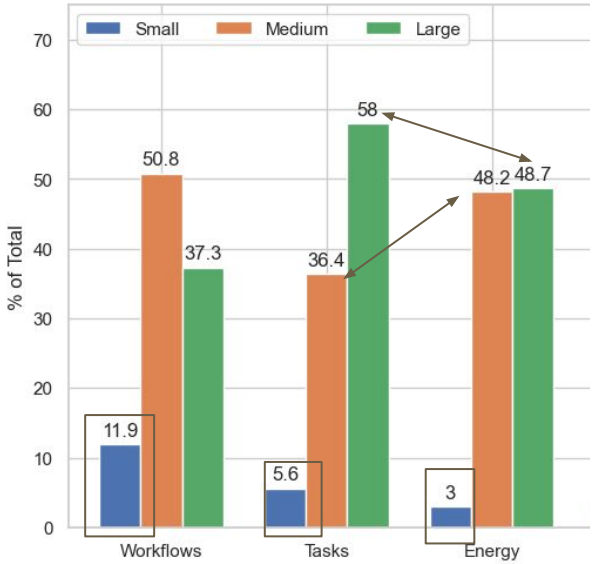
Energy Share of Tasks Managed by Maven or Gradle Over Total Workflow Energy

24-28 % of energy consumption of workflows are associated to **maven or gradle tasks**

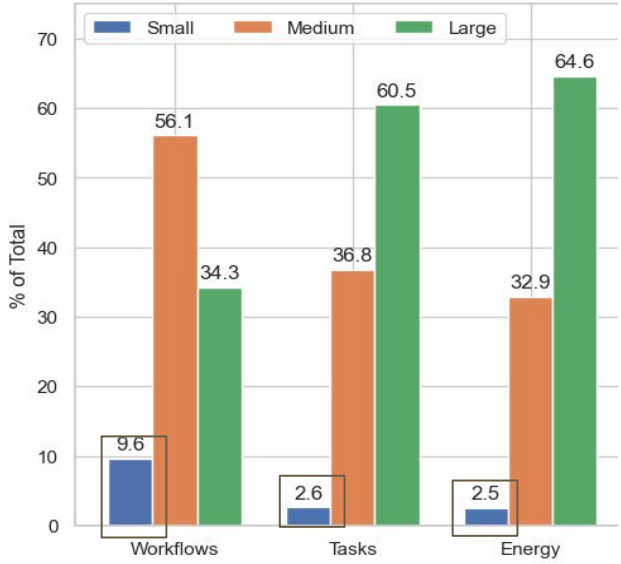
37-40 % for small project (< 10K LOC)

38-36 % for medium project (10K<x<100K LOC)

Proportion of total number of workflows, number of task and energy by project size (LoC)



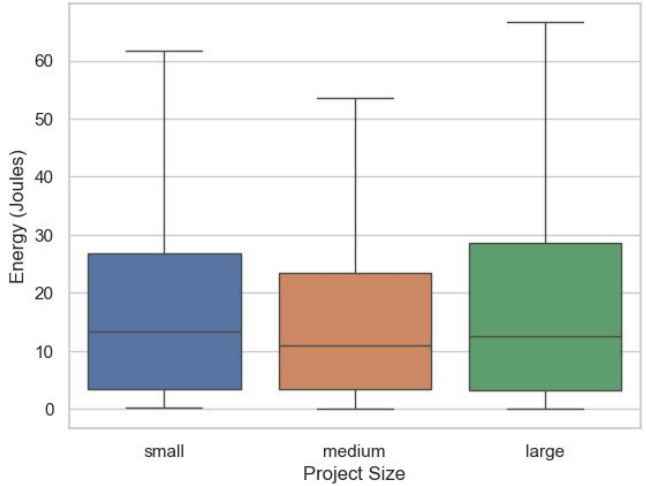
Maven



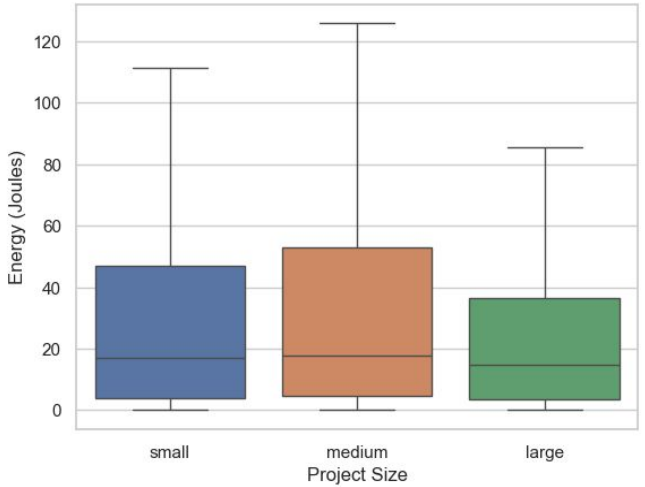
Gradle

Does the project size have an impact on the energy consumption of individual task ?

Energy Consumption of Maven and Gradle Tasks by projects size



Energy Consumption of **Maven** Tasks by Project Size



Energy Consumption of **Gradle** Tasks by Project Size

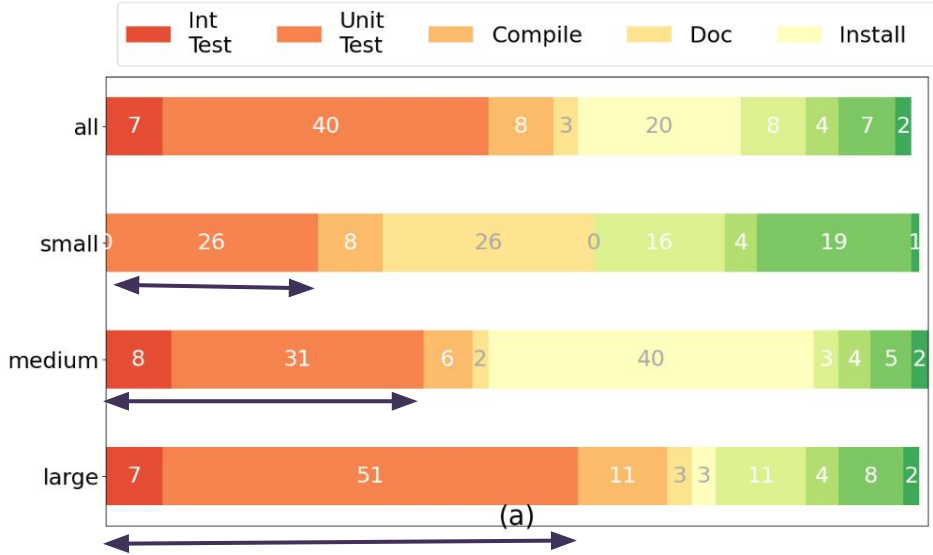
Influence of Project Size in Tasks' Energy Consumption

Tool	Comparison	p-value	Delta	Interpretation
Maven	Small x Medium	< .001	0.037	negligible
Maven	Small x Large	< .001	0.045	negligible
Maven	Medium x Large	< .001	0.012	negligible
Gradle	Small x Medium	.001	-0.057	negligible
Gradle	Small x Large	< .001	0.102	negligible
Gradle	Medium x Large	< .001	0.150	small

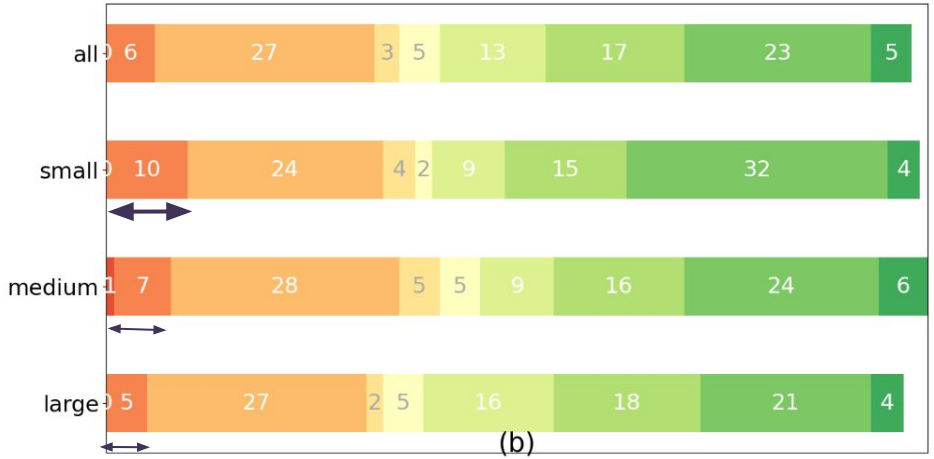
- Tasks from larger projects do not consume more energy than tasks from smaller projects

Comparison of the energy consumption of tasks from project of different size using **Mann-Whitney-Wilcoxon and Cliff's Delta**

Energy consumption profile by category of Maven tasks

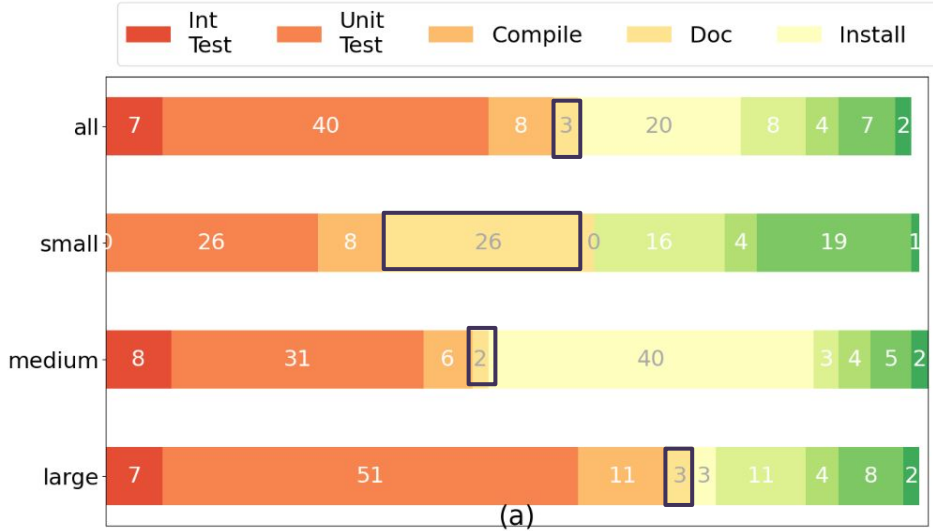


Cumulative Energy Consumption of Maven Tasks by Category



Proportion of Maven Tasks by Category

Energy consumption profile by category of Maven tasks



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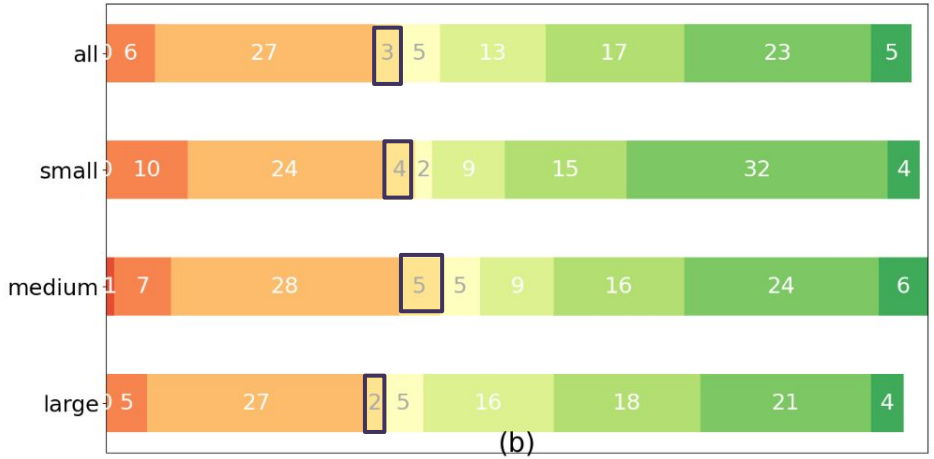
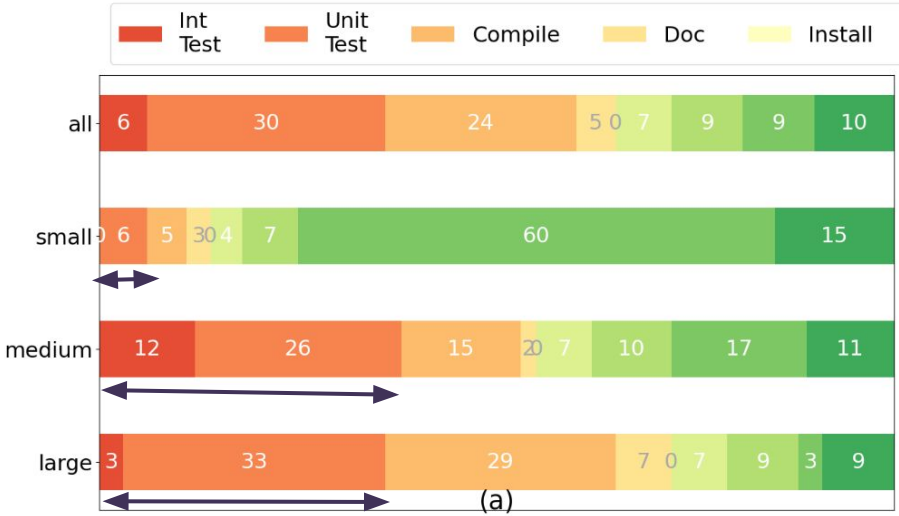
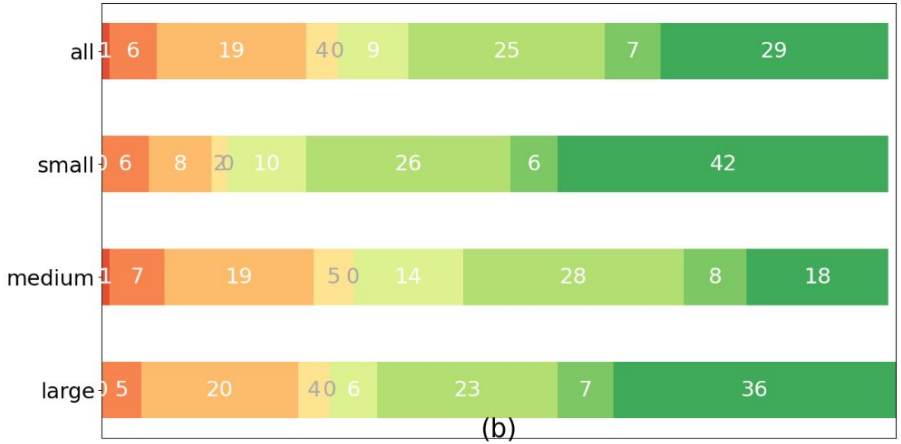


Proportion of Maven Tasks by Category

Energy consumption profile by category of Gradle tasks

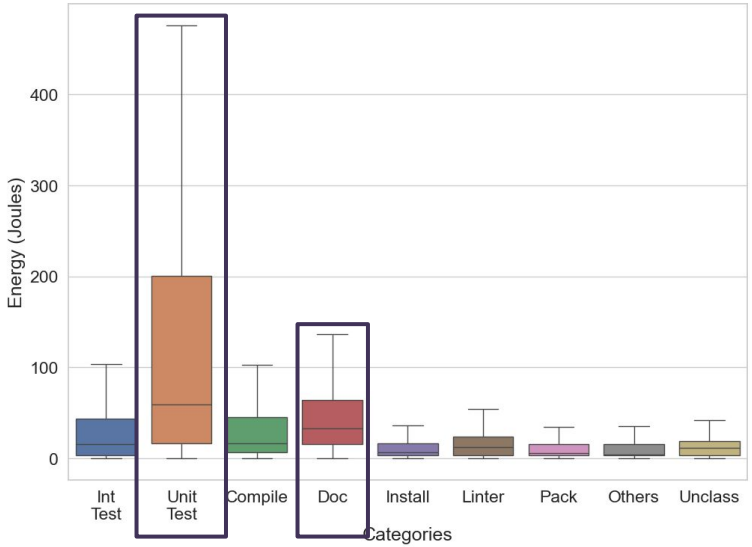


Cumulative Energy Consumption of Gradle Tasks by Category

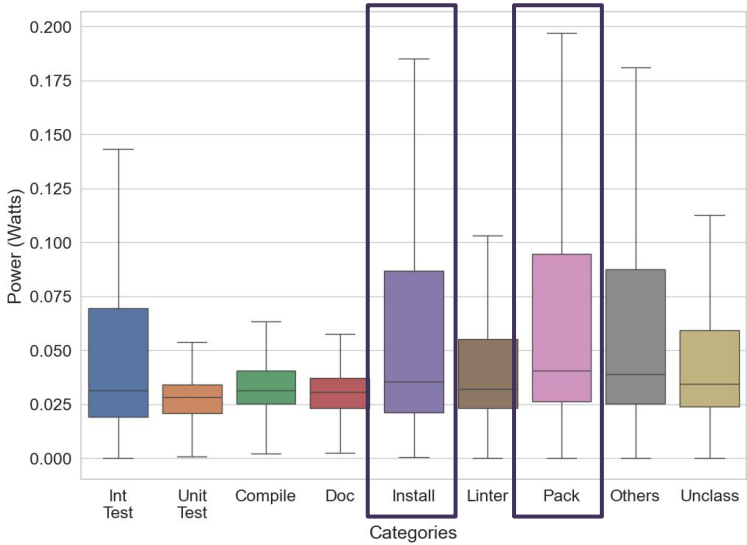


Proportion of Gradle Tasks by Category

Energy Consumption Profile Per Task and Per Unit of Time - Maven

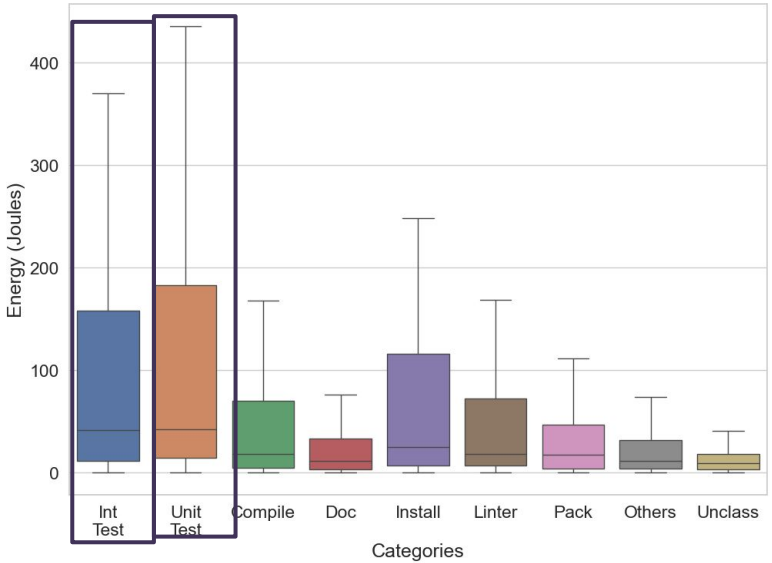


Energy Consumption of Maven Tasks by Category.

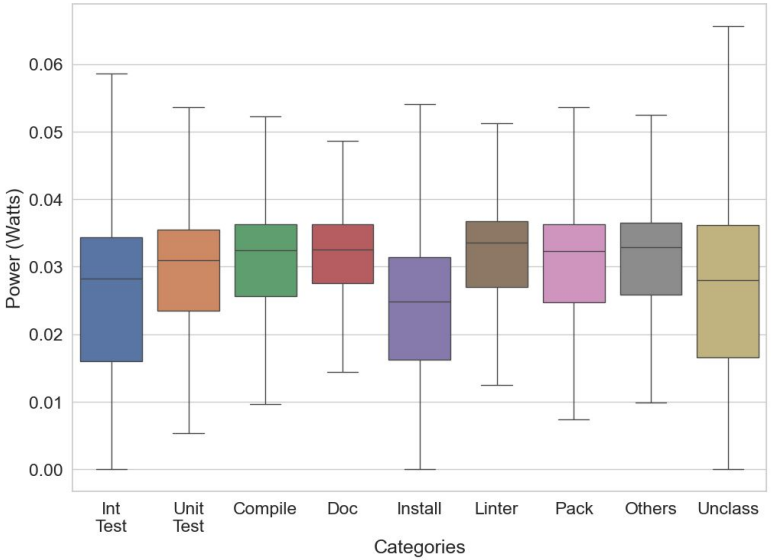


Power Dissipation of Maven Tasks by Category.

Energy Consumption Profile Per Task and Per Unit of Time - Gradle



Energy Consumption of Gradle Tasks by Category.



Power Dissipation of Gradle Tasks by Category.

Key points :

RQ1. How is the overall energy consumption associated with Maven/Gradle tasks?

- Tasks managed by Maven / Gradle represent 25% of their workflow energy consumption.
- The size of the project from which a task come do not impact its energy consumption.

RQ2. How is the energy consumption profile by category of Maven/Gradle task?

- Testing-related tasks are those that consume more energy.
- The larger the project, the higher their energy consumption related to testing.

Perspectives :

- Focus on the monitoring and optimization of test related task.
- Explore the effect of incremental build on CI energy consumption.
- Evaluate the impact of workflow optimization on energy consumption [5]
- Integrate this analysis in coarse grain analysis, with all workflows.

[5] Islem Bouzenia and Michael Pradel. 2024. Resource Usage and Optimization Opportunities in Workflows of GitHub Actions. In Proceedings of the IEEE/ACM 46th International Conference on Software Engineering (ICSE '24).

Image source

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