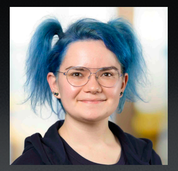
Enrique Barba Roque
E.BarbaRoque@tudelft.nl



Carolin Brandt
C.E.Brandt@tudelft.nl

Reliable cross-platform energy measurements with EnergiBridge

Tutorial at EASE 2026

What awaits?

- Introduction to EnergiBridge and how we use it for research & education
- Software energy measurements & how to conduct they reliably
- Try out the tool EnergiBridge yourself!

Carolin Brandt

TU Delft

Assistant Professor
Human- and Developer-centered Software Engineering

→ researching social & individual sustainability

Focus on **human-automation collaboration** and software quality.
Also looking into energy impact of **quality assurance**.

Teaching sustainable software engineering & software quality assurance
at Master / Bachelor level.

Enrique Barba Roque

TU Delft

PhD Candidate at SERG

Research on **Green AI**:

- **Energy** reporting and optimization of LLMs.

- Neuromorphic Computing and SNNs: New AI paradigm for low power implantable devices.

We want to get to know you too!

What are your plans for today’s session?

How interested and experienced are you with energy measurements?

Which tools did you use before to measure energy consumption?

Links & Installation Instructions for the Tutorial

- EnergiBrige: https://github.com/tdurieux/energibridge
  - Fork for Windows without vulnerability: https://github.com/enriquebarba97/EnergiBridge/tree/pawnio-migration

- Notebooks with configurations and data analysis for research example: https://github.com/enriquebarba97/EnergiBridge-tutorial

Research done with EnergiBridge

Insights into resource utilization of code small language models serving with runtime engines and execution providers☆

Francisco Durán [a], Matias Martinez [a], Patricia Lago [b], Silverio Martínez-Fernández [a,*]

[a] *Universitat Politècnica de Catalunya, Barcelona, Catalunya, Spain*
[b] *Vrije Universiteit Amsterdam, Amsterdam, Netherlands*

Impact of ML Optimization Tactics on Greener Pre-Trained ML Models

Alexandra González Álvarez [1], Joel Castaño [1], Xavier Franch [1], Silverio Martínez-Fernández [1*]

[1]Universitat Politècnica de Catalunya, Barcelona, Spain.

*Corresponding author(s). E-mail(s): silverio.martinez@upc.edu;
Contributing authors: alexandra.gonzalez.alvarez@upc.edu;
joel.castano@upc.edu; xavier.franch@upc.edu;

2025 IEEE/ACM 47th International Conference on Software Engineering (ICSE)

Unveiling the Energy Vampires: A Methodology for Debugging Software Energy Consumption

Enrique Barba Roque
Delft University of Technology
Delft, The Netherlands
enrique@ebarba.com

Luis Cruz
Delft University of Technology
Delft, The Netherlands
L.Cruz@tudelft.nl

Thomas Durieux
Delft University of Technology
Delft, The Netherlands
thomas@durieux.me

🏆 **Distinguished Paper ICSE '25**

The Energy Impact of Batch Testing in Continuous Integration: An Empirical Study of Static and Dynamic Batching Strategies

Máté Oszkó
M.Oszko-1@student.tudelft.nl
Delft University of Technology
Delft, The Netherlands

Xutong Liu
x.liu-14@tudelft.nl
Delft University of Technology
Delft, The Netherlands

Andy Zaidman
a.e.zaidman@tudelft.nl
Delft University of Technology
Delft, The Netherlands

Carolin Brandt
c.e.brandt@tudelft.nl
Delft University of Technology
Delft, The Netherlands

Can We Make Code Green? Understanding Trade-Offs in LLMs vs. Human Code Optimizations

POOJA RANI, University of Zurich, Switzerland
JAN-ANDREA BARD, University of Bern, Switzerland
JUNE SALLOU, Wageningen University & Research, The Netherlands
ALEXANDER BOLL, University of Bern, Switzerland
TIMO KEHRER, University of Bern, Switzerland
ALBERTO BACCHELLI, University of Zurich, Switzerland

On the Energy Cost of Static Analysis Precision: An Empirical Study of SpotBugs Effort Levels

Sophie van der Linden
sophievanderlinden001@gmail.com
Delft University of Technology
Delft, The Netherlands

Xutong Liu
x.liu-14@tudelft.nl
Delft University of Technology
Delft, The Netherlands

Carolin Brandt
c.e.brandt@tudelft.nl
Delft University of Technology
Delft, The Netherlands

Generating Energy-Efficient Code via Large-Language Models – Where are we now?

Radu Apsan[†], Vincenzo Stoico[†], Michel Albonico[⋆], Rudra Dhar[‡], Karthik Vaidhyanathan[‡], Ivano Malavolta[†]
[†] Vrije Universiteit Amsterdam, [⋆] Federal University of Technology of Paraná (UTFPR), [‡] IIIT Hyderabad
r.apsan@vu.nl,v.stoico@vu.nl,michelalbonico@utfpr.edu.br,rudra.dhar@research.iiit.ac.in
karthik.vaidhyanathan@iiit.ac.in,i.malavolta@vu.nl

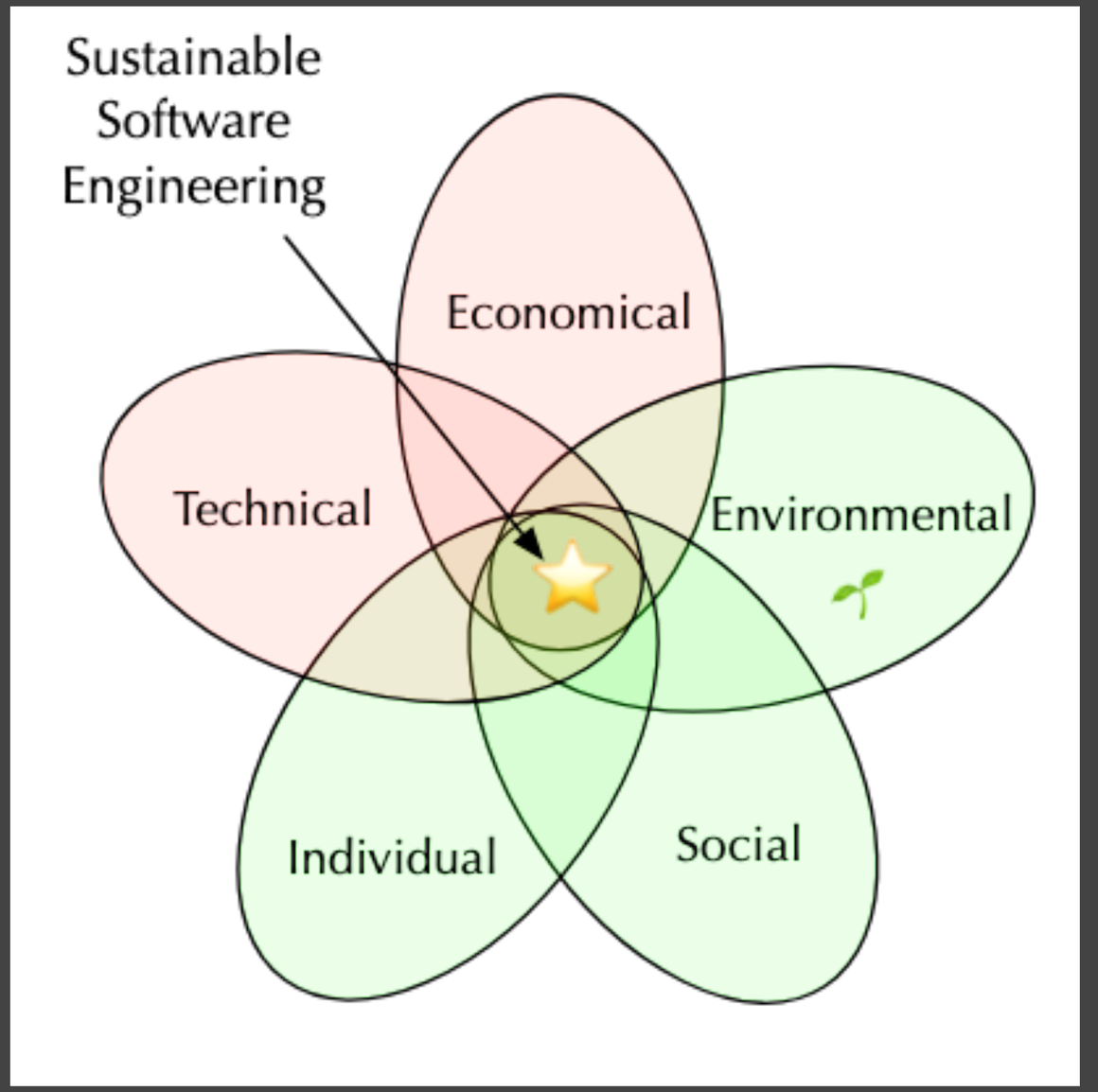
An Empirical Study on How Architectural Topology Affects Microservice Performance and Energy Usage

Irena Ristova, Vincenzo Stoico
Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
Email: i2.ristova@student.vu.nl, v.stoico@vu.nl

Teaching Sustainable Software Engineering

140 MSc Students

- Course developed by Luis Cruz in 2022
- https://luiscruz.github.io/course_sustainableSE/2026/
- Focus on **reliable energy measurements** also branching into social & individual sustainability (**society & developers**)
- Now mandatory in our SE “themes” in CS and AI Technology MSc



Schedule for Sustainable SE 2026

Lectures: Theory & Project Inspiration

	Monday	Tuesday	Wednesday	Thursday	Friday
	9	10	11	12	13
	08:45-10:45 Course introduction. Sustainable Software: What, Why and How.		08:45-10:45 Social and Individual Sustainability. (Theory + Study Ethics)	10:45-12:45 Lab. Measuring software energy consumption. Introduction to Project 1.	
3.2	16	17	18	19	20
	08:45-10:45 Green Software Engineering — Part I: Scientific guide for reliable energy measurements.		08:45-10:45 Green Software Engineering — Part II: units of energy.	10:45-12:45 Project 1 - steering meeting	
3.3	23	24	25	26	27
	08:45-10:45 Green Software Engineering — Part III: Energy efficiency in mobile computing; carbon-aware data centres.		08:45-10:45 Guest Lecture – GreenPT	10:45-12:45 Project 1 - steering meeting	EoD: Deadline P1, blog post + artifact, Buddycheck P1
3.4	2	3	4	5	
March	08:45-10:45 Green AI.		08:45-10:45 Sustainability Awareness Framework: Hands-on workshop	10:45-12:45 Workshop Topics P2	
3.5 - 3.8	Weekly Project 2 steering meetings				
3.8	30	31	1	2	3
				EoD: P2 deadline, paper + software + video, Buddycheck P2	
	6	7	8	9	
April		08:45 - 13:45 Presentations + Q&A	08:45 - 13:45 Presentations + Q&A		

Project 1: Measuring Software Energy Consumption

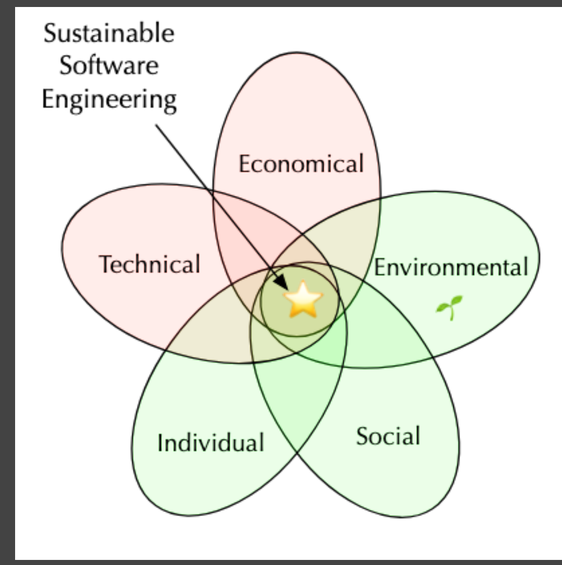
Project 2: Hacking Sustainability

All student reports are shared on the course website 🌳

Teaching Sustainable Software Engineering
140 MSc Students

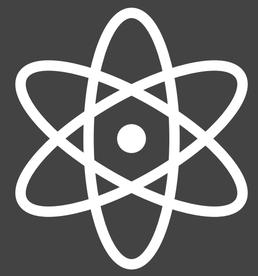
- Course developed by Luis Cruz in 2022
- https://luiscruz.github.io/course_sustainableSE/2026/
- Focus on reliable energy measurements
  also branching into social & individual sustainability (society & developers)

- 2 Projects: Measuring Software & Hacking Sustainability
- Student reports are shared on the website 🌳



Project 1

Measuring Software Energy Consumption



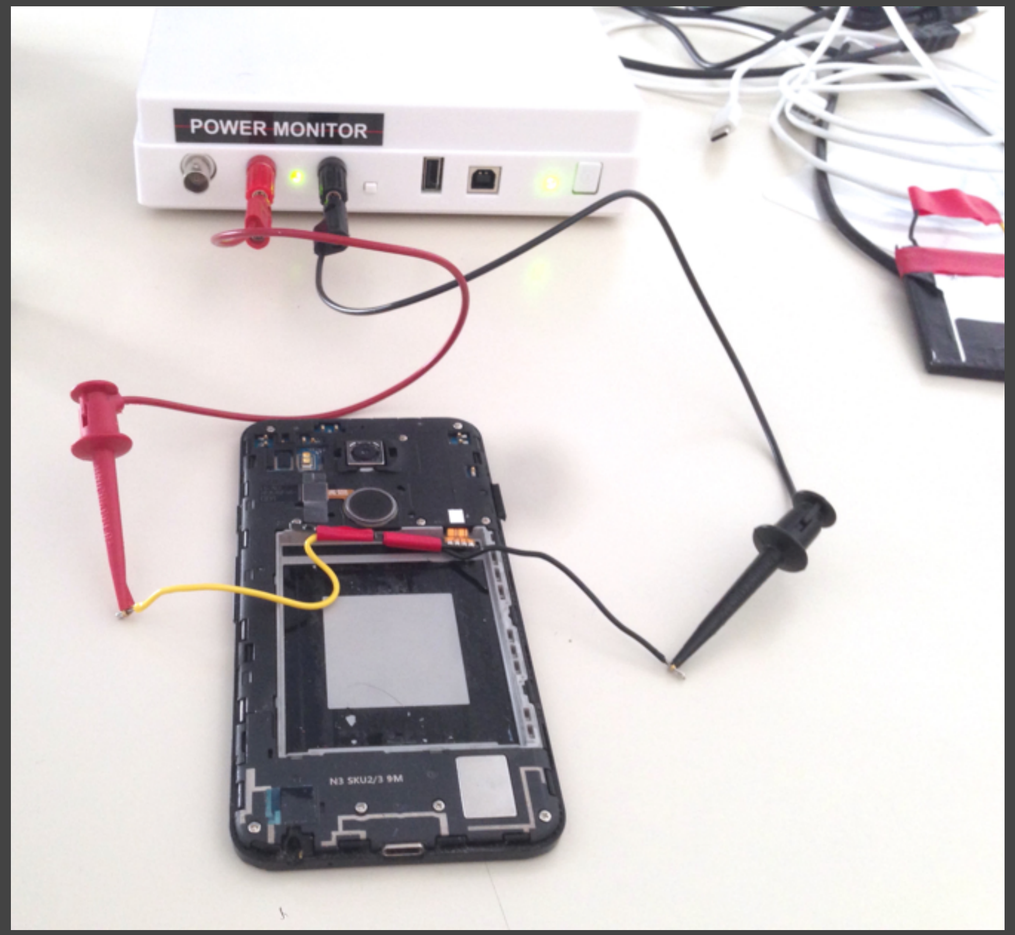
- **Goal:** Measure the energy consumption of software applications.
- **Approach**: energy measurement tools; use case testing.
- **Deliverables:**
  - blog-style report (approx. 2500 words)
  - Artifact (code / scripts)
  - Buddycheck P1
- **Length:** 3 weeks
- **Formative feedback:** 2 lab sessions
- **Group size**: 4, randomly assigned

https://luiscruz.github.io/course_sustainableSE/2026/ checkout projects 9 and 16

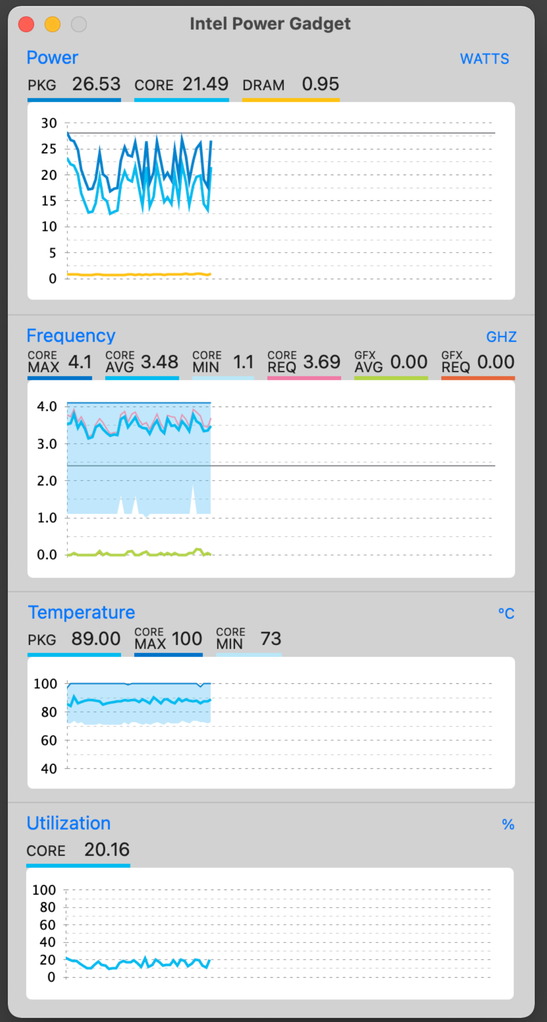
Software Energy Measurements

Intro to EnergiBridge

Hardware Power Monitors

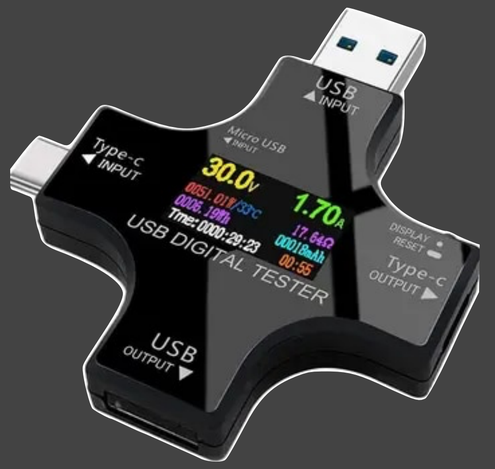


Energy Profilers



Hardware Power Monitors

- Connects directly to the power source of the device/ component.
  - Some power monitors also replace the power source.
- Example:
  - **Monsoon Power Monitor** (for IoT and smartphones).
    - Can be fully automated using a Python API.
    - It measures and powers small electronic devices.
- There are many power/energy meters out there but for **software use cases** we need to be able to **control them using an API**.

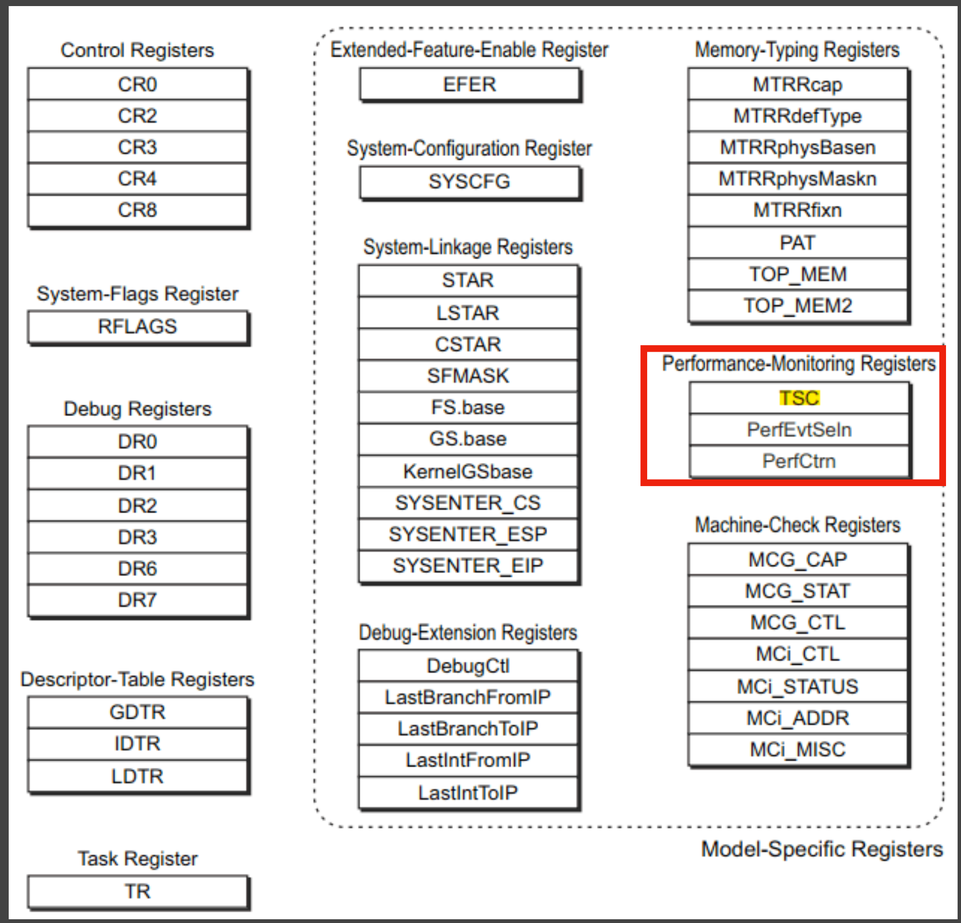


Energy Profilers

- **Simple setup**! Quite reliable (if you choose the profiler wisely).
  - Recently, they are starting to rely on internal power sensors.
- Still **sensitive to noise** from concurrent processes/tasks! ⚠️

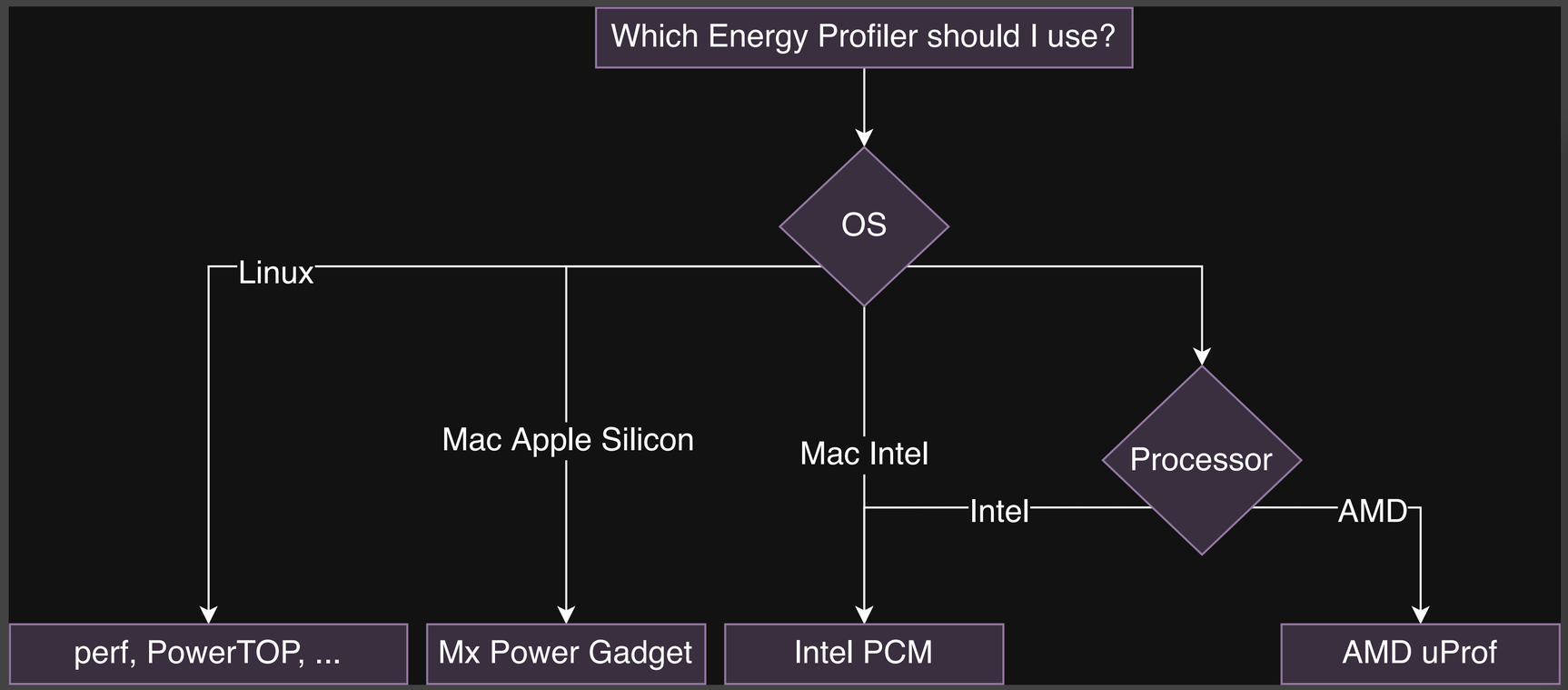
Intel/AMD Profilers

- CPU profilers are based on **Model-Specific Registers** (MSR)
  - They report performance metric and control certain CPU features
- **Linux**: Available in /dev/cpu/*/msr with root access
- **Windows**: Requires a kernel-level driver

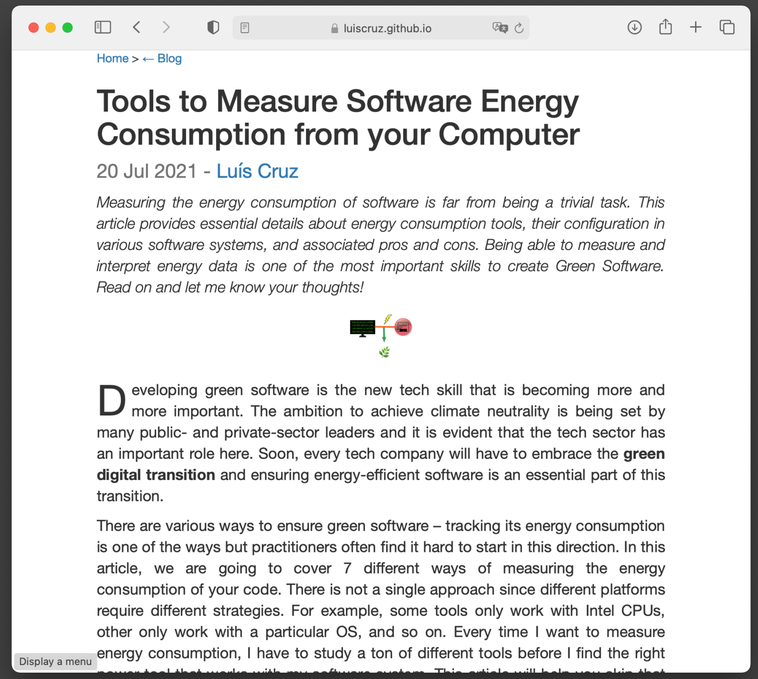


Intel/AMD Profilers

- Linux: many tools with AMD and Intel support:
  - perf, PowerTOP, …
- Windows: Depends on your processor
  - **Intel Performance Counter Monitor (PCM)**: https://github.com/intel/pcm
  - AMD uProf: https://www.amd.com/en/developer/uprof.html
- Apple Silicon Macs: **Mx Power Gadget**. https://www.seense.com/menubarstats/mxpg/



🔗 https://luiscruz.github.io/2021/07/20/measuring-energy.html

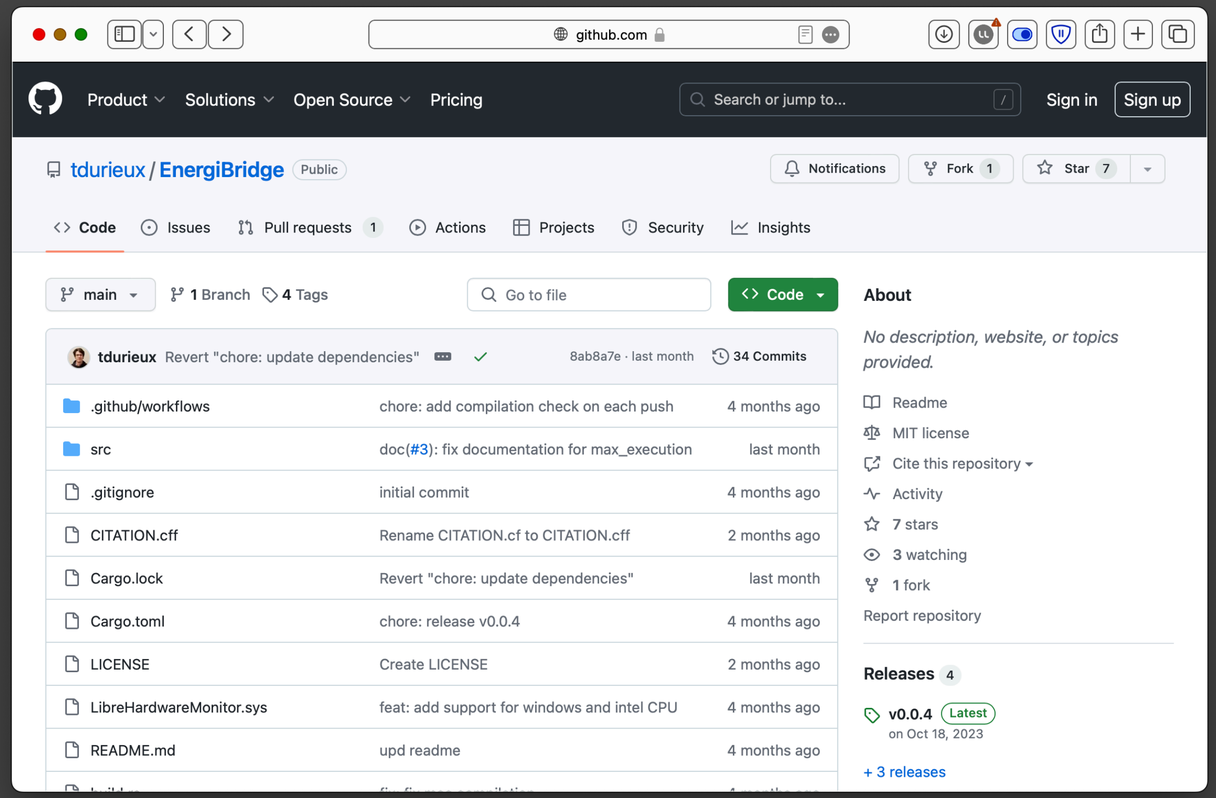


(Missing Apple m1 tools: mxpg, powermetrics)

EnergiBridge

https://github.com/tdurieux/energibridge

edu.nl/uraup




```
> target/release/energibridge -o results.csv --summary sleep 10
```

How does it work?

- EnergiBridge relies on the previously presented tools to read energy data from hardware.
  - CPU: MSR registers
  - GPU: Nvidia NVML

How does it work?

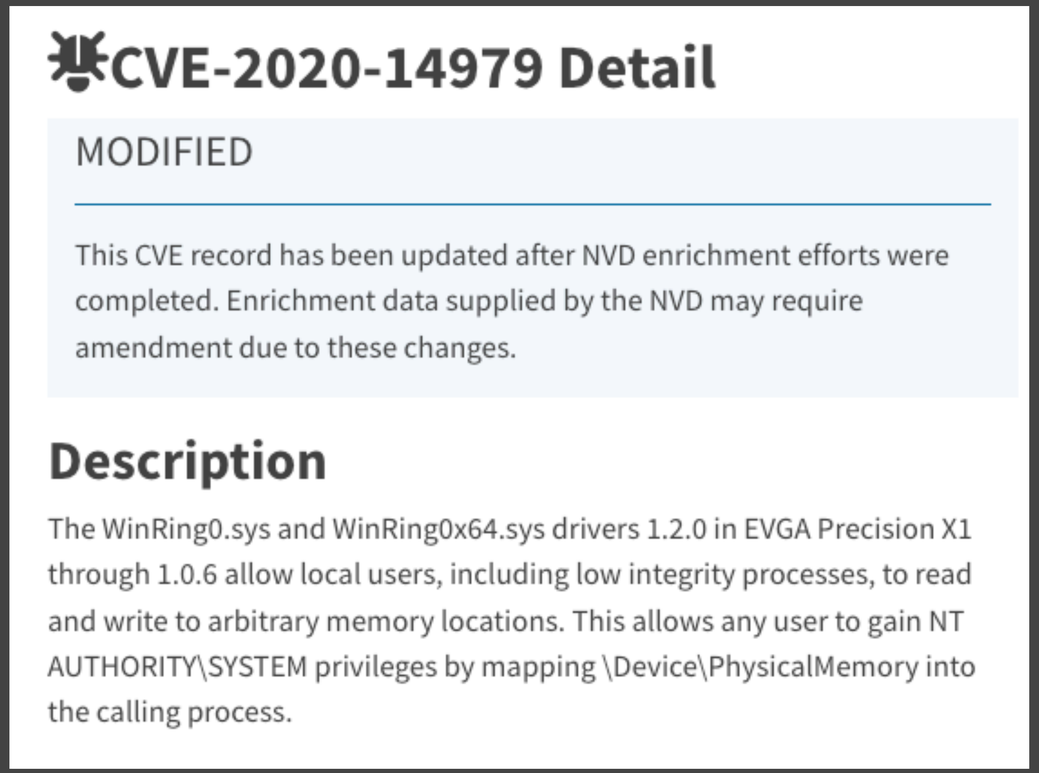
- Linux: MSR registers are available in /dev/cpu/{cpu_number}/msr.
  - They require root access or udev rules

```
sudo groupadd -f mer
sudo usermod -aG mar $USER

sudo chgrp -R msr /dev/cpu/*/msr
sudo chmod g+r /dev/cpu/*/msr

/etc/udev/rules.d/99-msr.rules
```

```
SUBSYSTEM==“msr”, GROUP=“msr”, MODE=“0640”
```

EnergiBridge on Windows

- EnergiBridge currently uses the WinRing0 kernel driver to access MSR
- There is a known **vulnerability** with this driver.
- Use EnergiBridge on Linux when possible.
  - PR not yet merged, you can test the fork.



CVE-2020-14979 Detail

MODIFIED

This CVE record has been updated after NVD enrichment efforts were completed. Enrichment data supplied by the NVD may require amendment due to these changes.

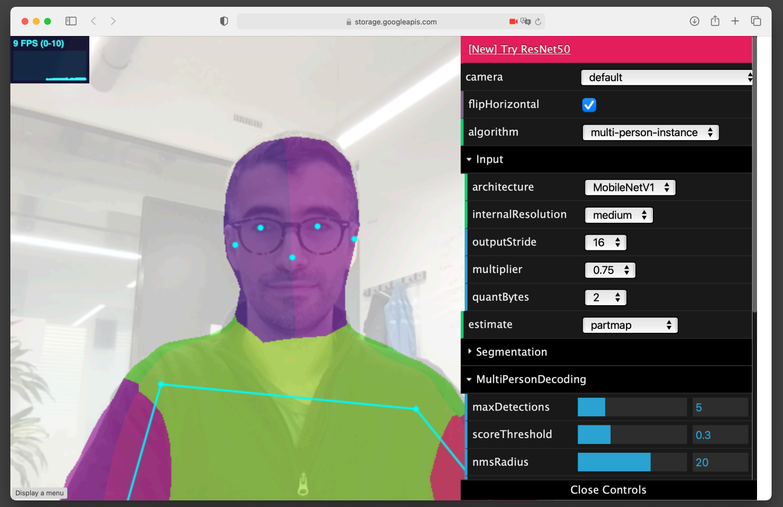
Description

The WinRing0.sys and WinRing0x64.sys drivers 1.2.0 in EVGA Precision X1 through 1.0.6 allow local users, including low integrity processes, to read and write to arbitrary memory locations. This allows any user to gain NT AUTHORITY\SYSTEM privileges by mapping \Device\PhysicalMemory into the calling process.

How does it work?

- Windows: Accessing MSR registers requires kernel-level access
  - PawnIO: Kernel-level driver to access registers
  - Requires running EnergiBridge on an Administrator CMD
  - Windows Defender complains sometimes

Hands-on 1



- **Install** your energy profiler (EnergiBridge).
- **Collect** the energy data of using **Coral BodyPix** for **30 seconds**.
  https://storage.googleapis.com/tfjs-models/demos/body-pix/index.html

```
enrique@Enriques-MacBook-Pro EnergiBridge-fork % ./target/release/energibridge -o test.csv --summary sleep 30
Energy consumption in joules: 621.5121655483244 for 30.196638 sec of execution.
enrique@Enriques-MacBook-Pro EnergiBridge-fork %
```

```
target/release/energibridge -o results.csv --summary sleep 30
```

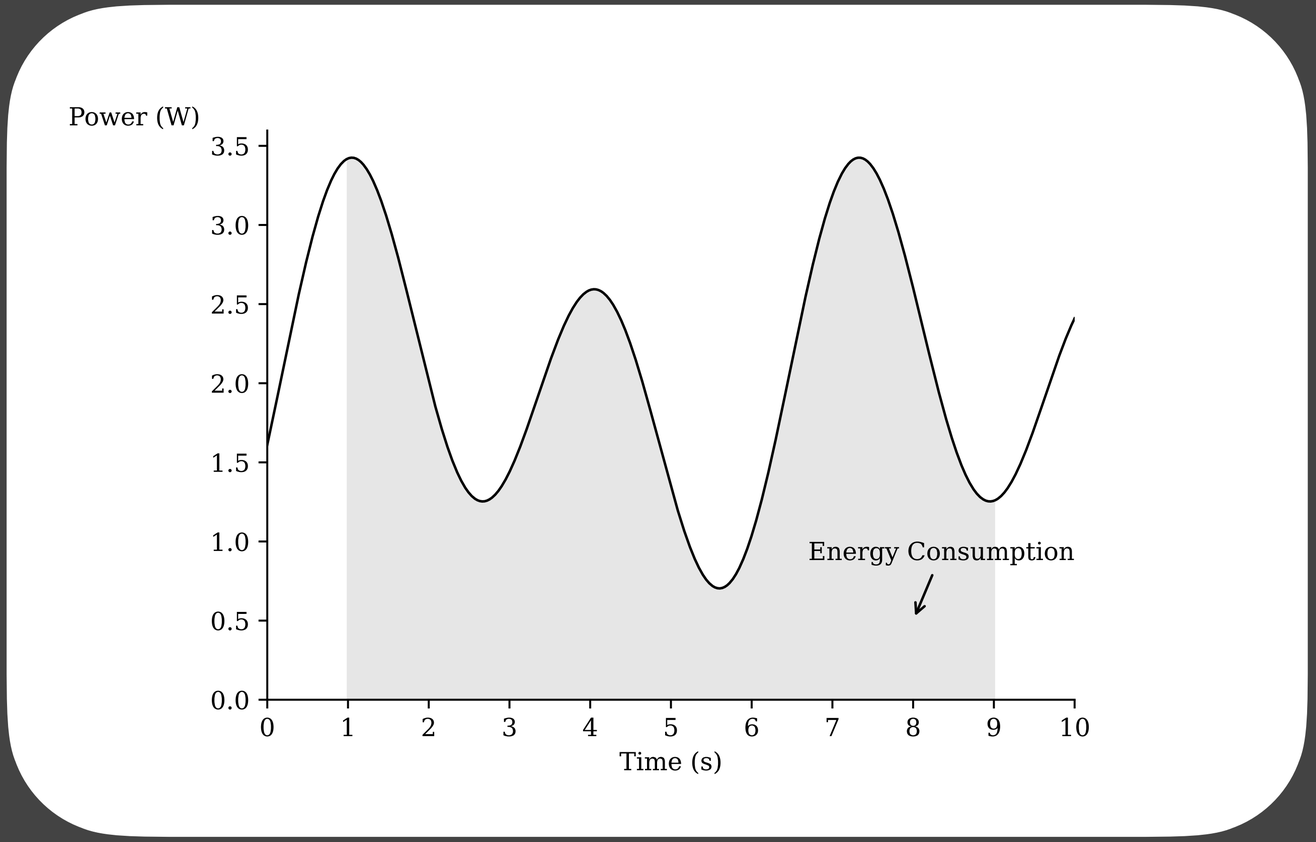
How to interpret EnergiBridge output?

Delta	Time	CORE0_ENERGY (J)	CORE0_FREQ (MHZ)	CORE0_PSTATE	CORE0_VOLT (V)	CORE10_ENERGY (J)	CORE10_FREQ (MHZ)
0	1721123585034	2490352.354675293	4700	1	0.30000000000000004	1207996.7010040283	4700
99	1721123585035	2490352.3565368652	4700	1	0.30000000000000004	1207996.704788208	4700
99	1721123585135	2490352.632369995	4700	1	0.30000000000000004	1207996.8225250244	4700
99	1721123585235	2490352.6747131348	4700	1	0.30000000000000004	1207996.8478546143	4700
99	1721123585335	2490352.79876709	4700	1	0.3125	1207996.9600219727	4700
99	1721123585435	2490352.9552764893	4700	1	0.30000000000000004	1207997.0601043701	4700
99	1721123585535	2490353.0979156494	4700	1	0.3062499999999999	1207997.185684204	4700
99	1721123585635	2490353.225265503	4700	1	0.30000000000000004	1207997.3303527832	4700
99	1721123585735	2490353.4315338135	4700	1	0.3062499999999999	1207997.547454834	4700
99	1721123585835	2490353.495513916	4700	1	0.30000000000000004	1207997.661682129	4700
99	1721123585935	2490353.5417938232	4700	1	0.30000000000000004	1207997.6924743652	4700
99	1721123586035	2490353.718460083	4700	1	0.30000000000000004	1207997.784286499	4700
99	1721123586135	2490353.7224578857	4700	1	0.30000000000000004	1207997.883102417	4700
99	1721123586235	2490353.72706604	4700	1	0.30000000000000004	1207997.9824829102	4700
99	1721123586335	2490353.731277466	4700	1	0.30000000000000004	1207998.1005249023	4700

- EnergiBridge outputs a CSV with each row being a data sample in time
  - What are the columns?
- https://github.com/enriquebarba97/EnergiBridge-tutorial/blob/main/basic-analysis.ipynb

Energy and Power

- **Energy**: Work required to move electric charge
  - Measured in Joules (J)
- **Power**: Amount of energy per unit of time
  - Measured in Watts (W = J/s)



Energy and Power

Which energy metric makes most sense to measure for the following workloads?

How do we make energy measurements reliable?

Photo by Moritz Lange on Unsplash

Energy measurements are flaky

- Multiple runs might yield different results
- There are many **confounding factors** that need to be ~~controlled~~/**minimized**.

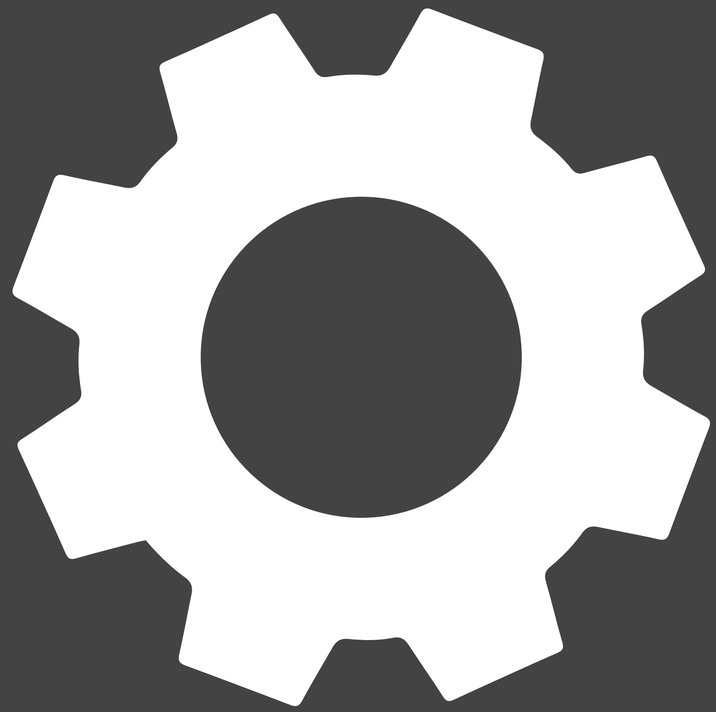
What could change your energy measurements' outcome?

Zen mode 🧘🏾

- **Close all applications.**
- **Turn off notifications.**
- **Only the required hardware** should be connected (avoid USB drives, external disks, external displays, etc.).
- **Kill unnecessary services** running in the background (e.g., web server, file sharing, etc.).
- If you do not need an internet or intranet connection, **switch off your network.**
- Prefer a **wired network connection** over wireless → more stable energy readings.

Freeze and report your settings 🥶

- Fix display brightness; **switch off auto brightness**
- If Wifi is on, it should always be on, connected to the same network/endpoint….



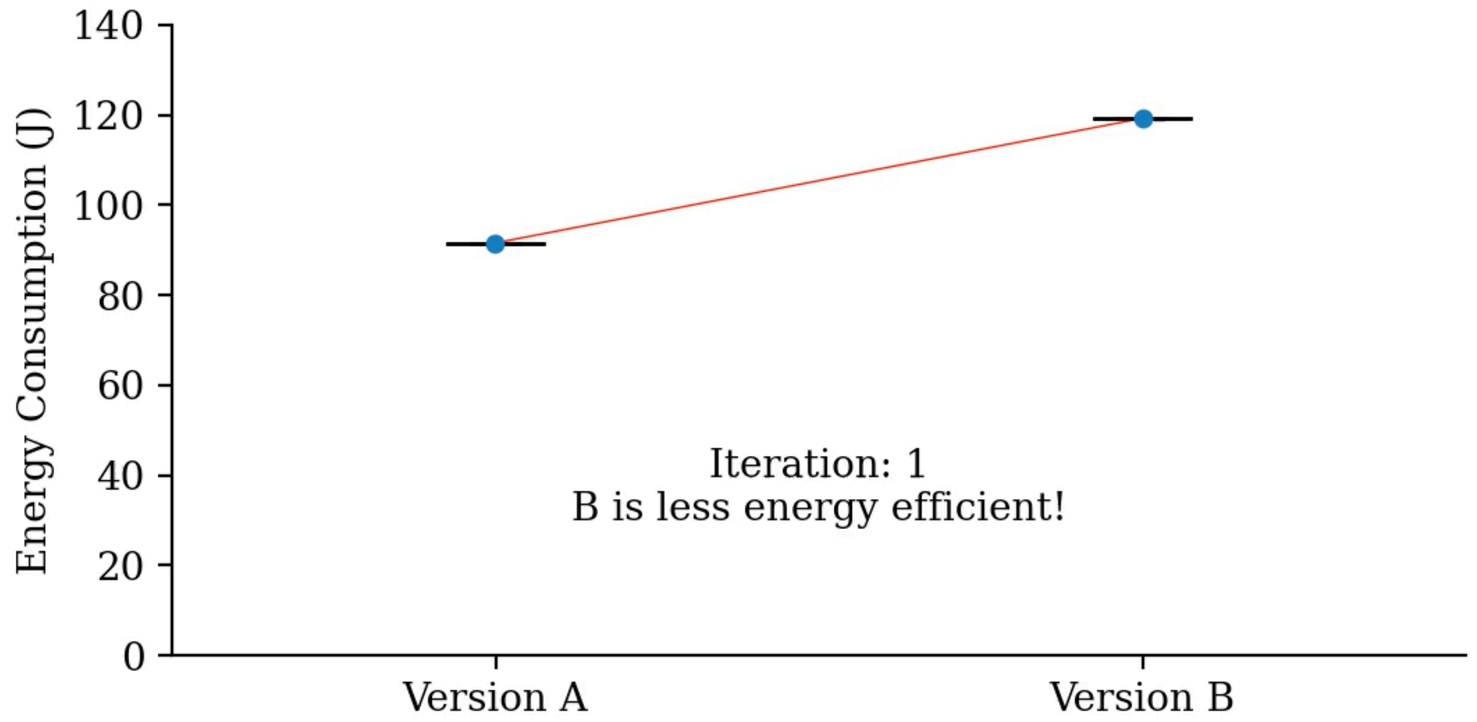
Keep it cool 🌡️

- Always make sure there is a **stable room temperature**.
- Tricky because, some times, experiments may have to run over a few days.
- If you cannot control room temperature: **collect temperature data** and **filter out** measurements where the room temperature is clearly deviating.

Warm-up 📶

- Energy consumption is highly affected by the **temperature of your hardware**.
- **Higher the temperature** -> higher the resistance of electrical conductors -> -> higher dissipation -> **higher energy consumption.**
- The first execution will appear more efficient because the hardware is still cold.
- Run a **CPU-intensive task** before measuring energy consumption. E.g., Fibonacci sequence. At least 1min; 5min recommended.

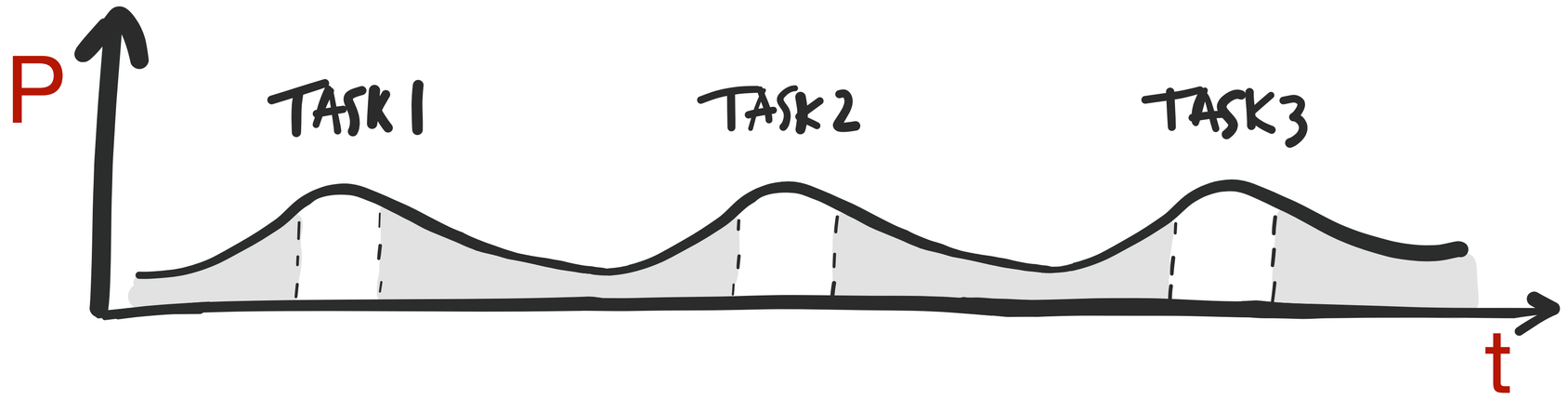
Iterations


Energy Consumption (J)
140
120
100
80
60
40
20
0
Iteration: 1
B is less energy efficient!
Version A
Version B

Repeat 🔁

- The best way to make sure a measurement is **valid** is by **repeating** it.
- In a scientific project, the **magic number is 30.**
- If you have many data samples, don’t repeat on each data sample.

Tail Energy Consumption



Rest II

- It is **common practice** to do a pause/sleep between executions/ measurements.
- Prevent **tail energy consumption** from previous measurements. ?
- Prevent collateral tasks of previous measurement from affecting the next measurement.
- There is no golden rule but **one minute** should be enough. It can be more or less depending on your **hardware** or the **duration** of your energy test.

Shuffle 🔀

- It is not a mystery that energy consumption depends on so many factors that it is impossible to control all of them.
- If you run 30 executions for version A and another batch for version B:
  - **External conditions that change over time** will have a **different bias** in the 2 versions (e.g., room temperature changes).
  - Randomizing the order distributes bias more evenly → fairer comparison.

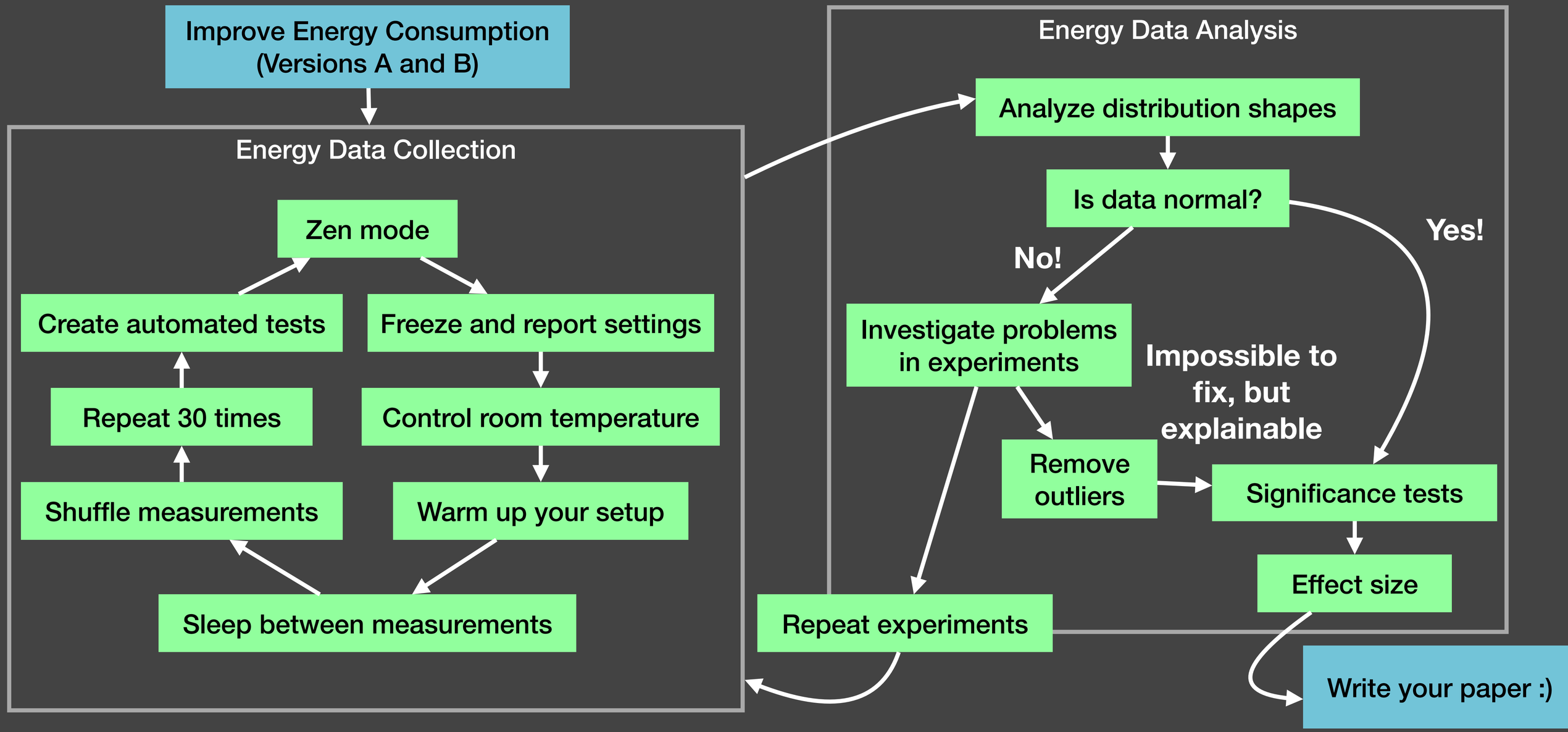
Automate Executions 🤖

- One cannot run 30 shuffled experiments per version without automation…
  - Time-consuming
  - Humans won’t keep it consistent.

Overview Reliable Energy Measurements

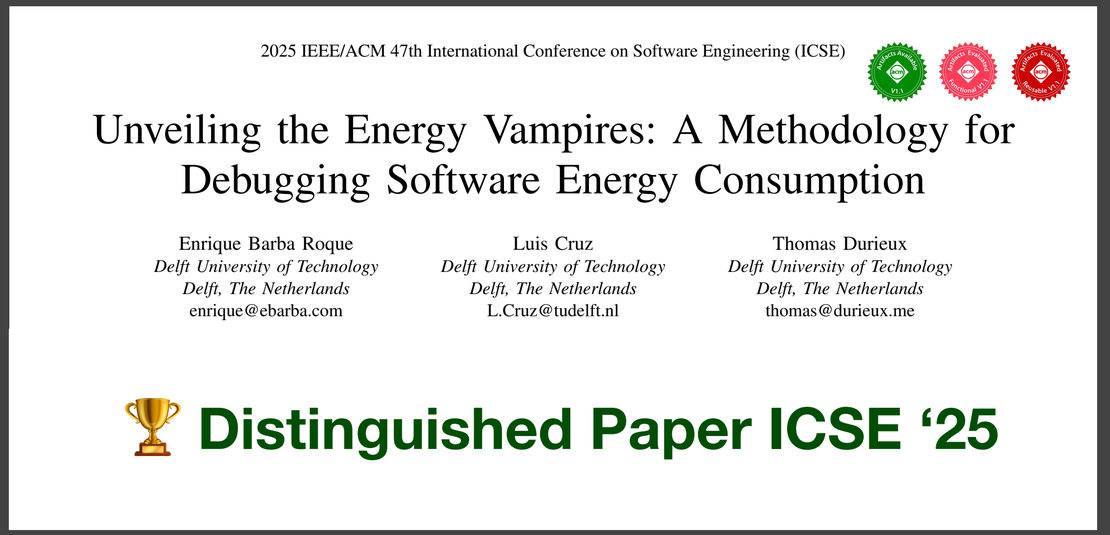
What should you do to make your energy measurements reliable?

Overview Reliable Energy Measurements



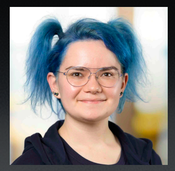
Hands-on 2
Research Example

- Pinpoint energy hotspots in different Redis configurations
- Notebook with short 2-config example and analysis.
- https://github.com/enriquebarba97/EnergiBridge-tutorial



edu.nl/yq7re

Enrique Barba Roque
E.BarbaRoque@tudelft.nl



Carolin Brandt
C.E.Brandt@tudelft.nl

Thank you for joining us!

Reliable cross-platform energy measurements with EnergiBridge

Tutorial at EASE 2026