Energieeffizienz von Backend-Architekturen

David Kopp

Green IT Consultant

envite consulting GmbH

envite

Copernicus-Auswertung

Heißester Juni seit Aufzeichnungsbeginn

Stand: 08.07.2024 09:06 Uhr

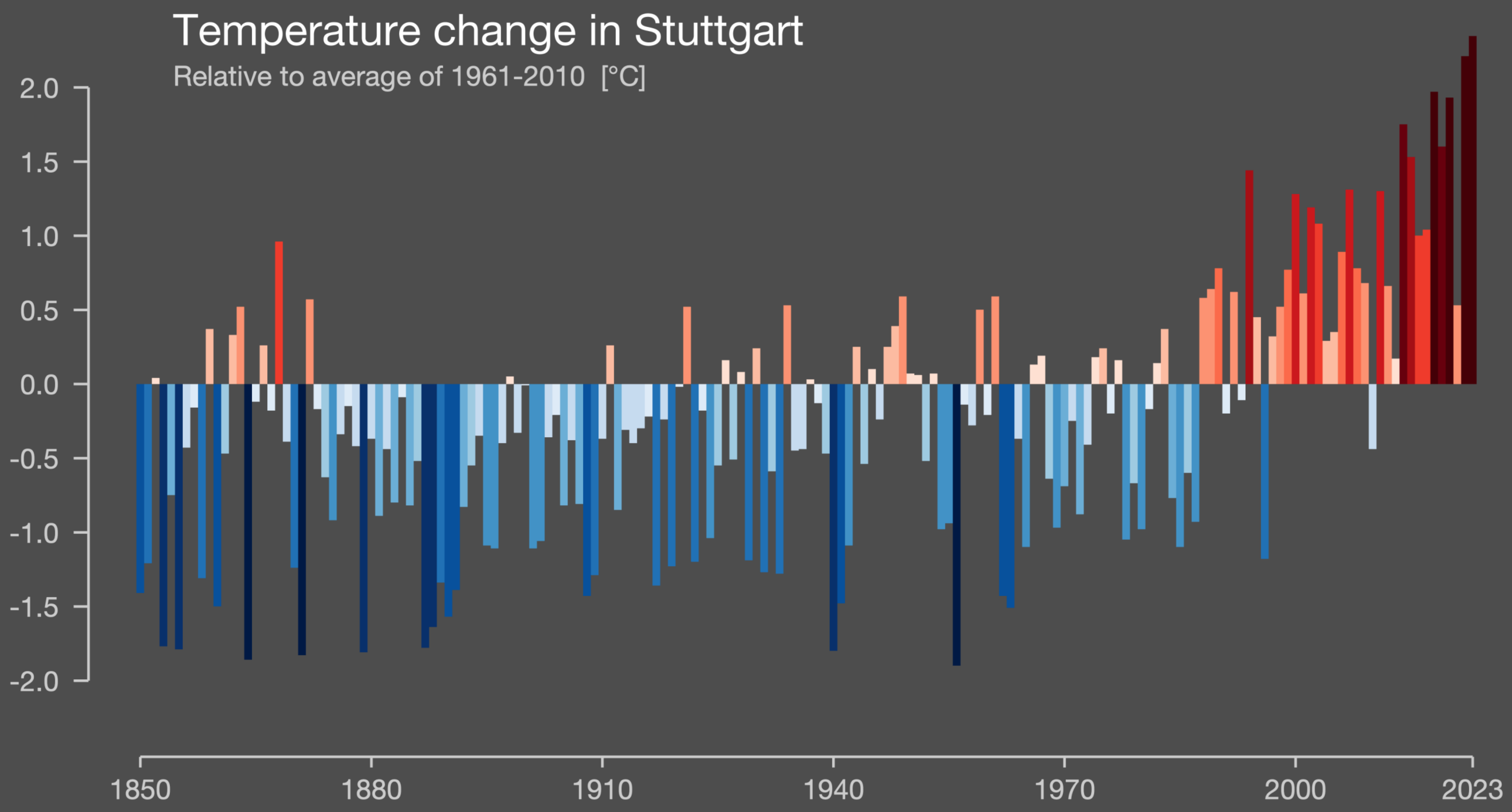
Auch wenn es sich in Deutschland anders anfühlte: Der Juni war global laut EU-Klimawandeldienst Copernicus der wärmste Juni seit Aufzeichnungsbeginn. Dies sei ein Beleg für die "fortdauernde Veränderung unseres Klimas".

Der vergangene Monat war - weltweit gesehen - der wärmste Juni seit Beginn der Datenaufzeichnungen. Wie der EU-Klimawandeldienst Copernicus mitteilte, lagen die Temperaturen im vergangenen Monat 1,5 Grad über dem geschätzten Juni-Durchschnitt der Jahre 1850 bis 1900, der vorindustriellen Referenzperiode. Damit war es der zwölfte Monat in Folge, der die 1,5-Grad-Schwelle erreichte oder überschritt.

Im Pariser Klimaschutzabkommen hatten sich Deutschland und viele andere Staaten Ende 2015 das Ziel gesetzt, die Erderwärmung deutlich unter zwei Grad zu halten, möglichst aber auf 1,5 Grad im Vergleich zur vorindustriellen Zeit zu begrenzen.

[Tag24]

[Haw24]


Temperature change in Stuttgart
Relative to average of 1961-2010 [°C]
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1850
1880
1910
1940
1970
2000
2023

Climate Crisis – Responsibility of the ICT Sector

ICT's carbon footprint?

- 2.1 – 3.9 % of global GHG emissions

Main GHG sources?

- Operation: Energy consumption
- Manufacturing: Embodied carbon

Renewable energies?

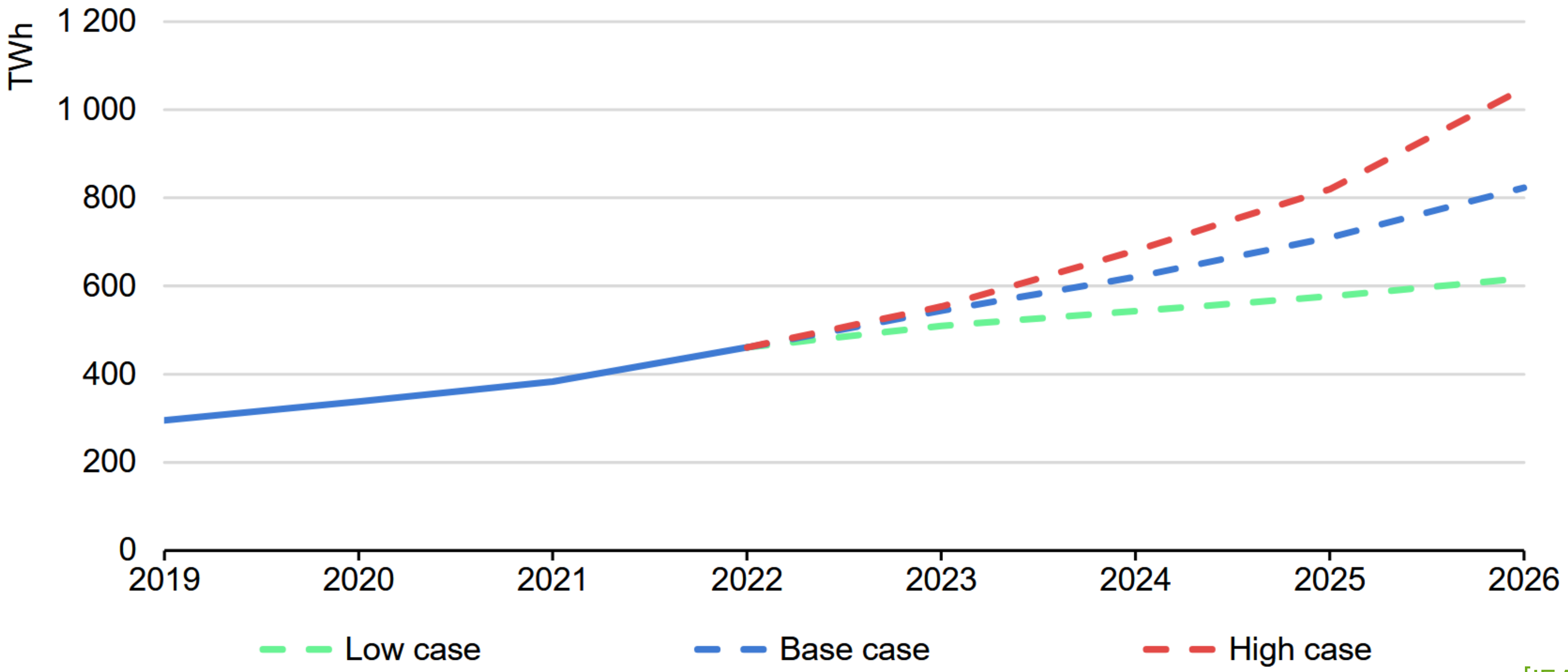
- Required for other purposes
- Does not solve all environmental issues

Consequence?

- Drastic decrease in energy demand and emissions necessary

[FBW+21]

Energy Demand of Data Centers



[IEA24]

[GSF22]

Green Software Principles

Energy Efficiency

Consume the least amount of electricity possible

Hardware Efficiency

Use the least amount of embodied carbon possible

Carbon Awareness

Do more when the electricity is clean and less when it's dirty

Green Software Foundation

greensoftware.org

Approach & Overview

Approach

- Comparison of cloud-based architecture styles
- **Focus:** Modular Monolith vs. Microservices
- **Metric:** Energy Efficiency

Reference Application

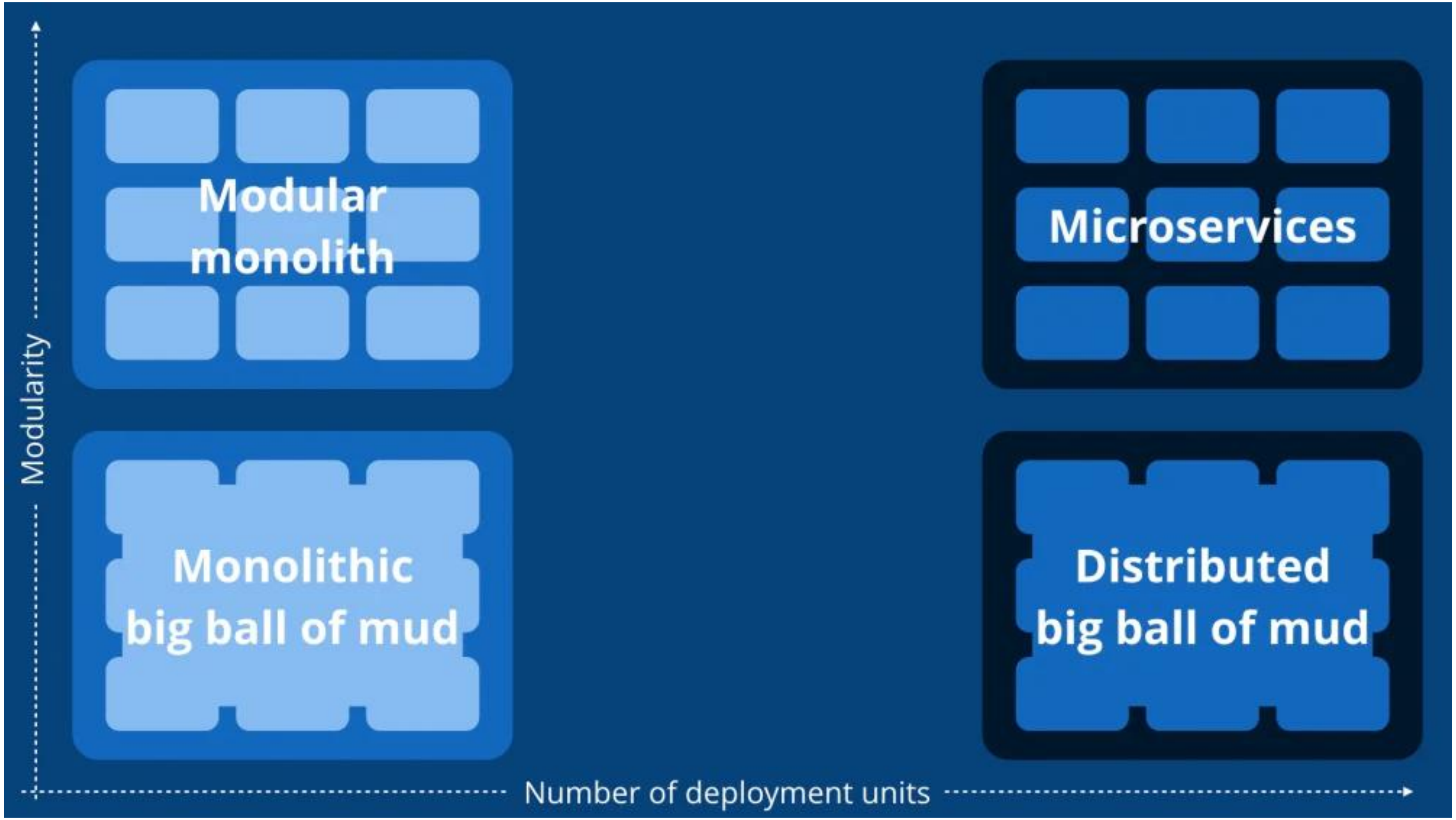
- **Microservices:** T2-Project (implementing saga pattern)
- **Modular Monolith:** Own implementation

Measurement & Analysis

- **Measurement Environments:**
  1. Green Metrics Tool
  2. Kubernetes & Kepler

Modular Monolith vs. Microservices

Why Comparing These Two Architecture Styles?



[Bro18]

Related Work

Monolith vs. Microservices in Terms of Performance

Monolith

- Better throughput under **low load**
- Lower response times (no overhead through network communication)

Microservices

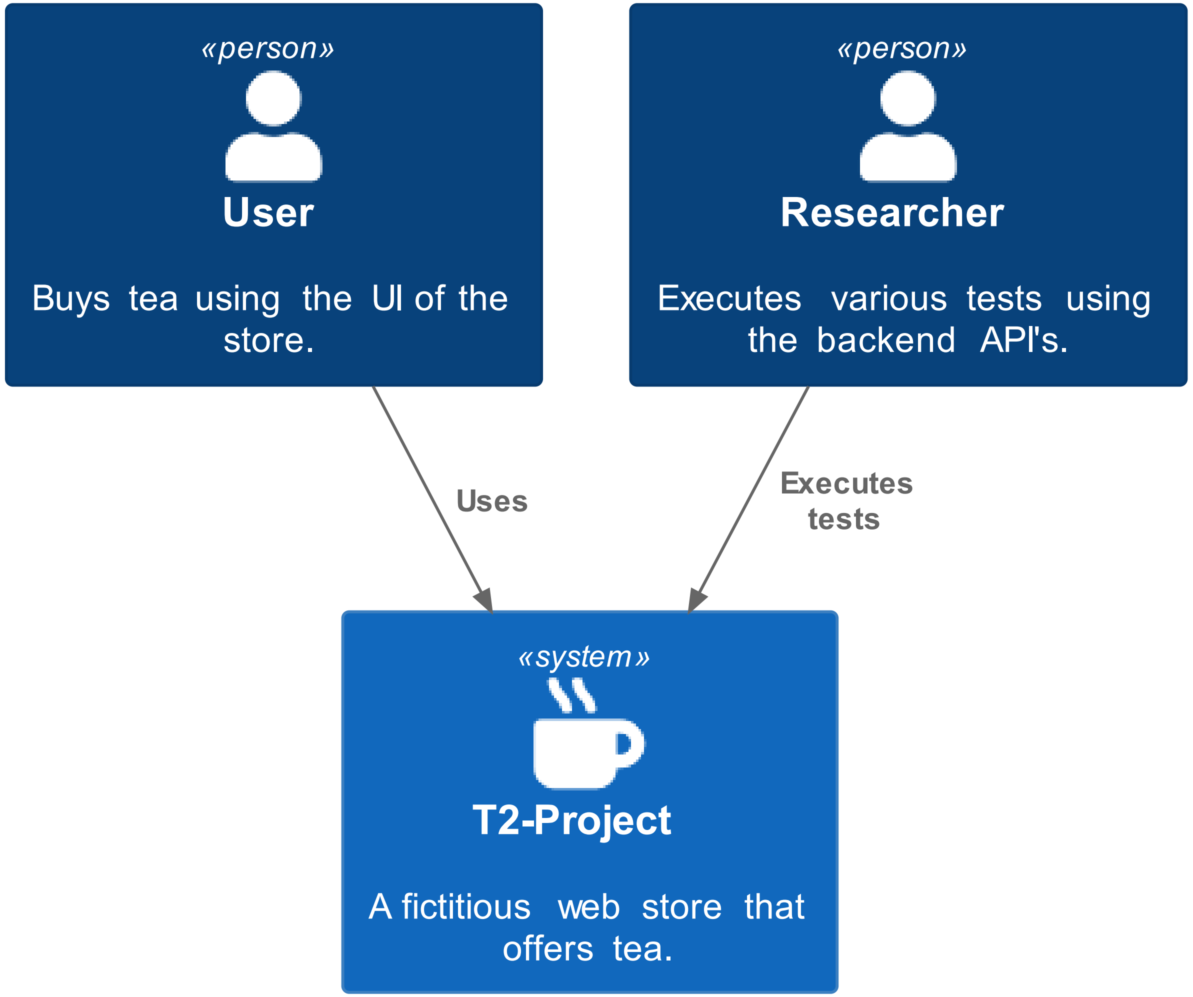
- Better throughput under **high load** (especially in compute-intensive scenarios)
- Better scalability (due to smaller components)

Papers are listed on slide References for Related Work

Reference Application

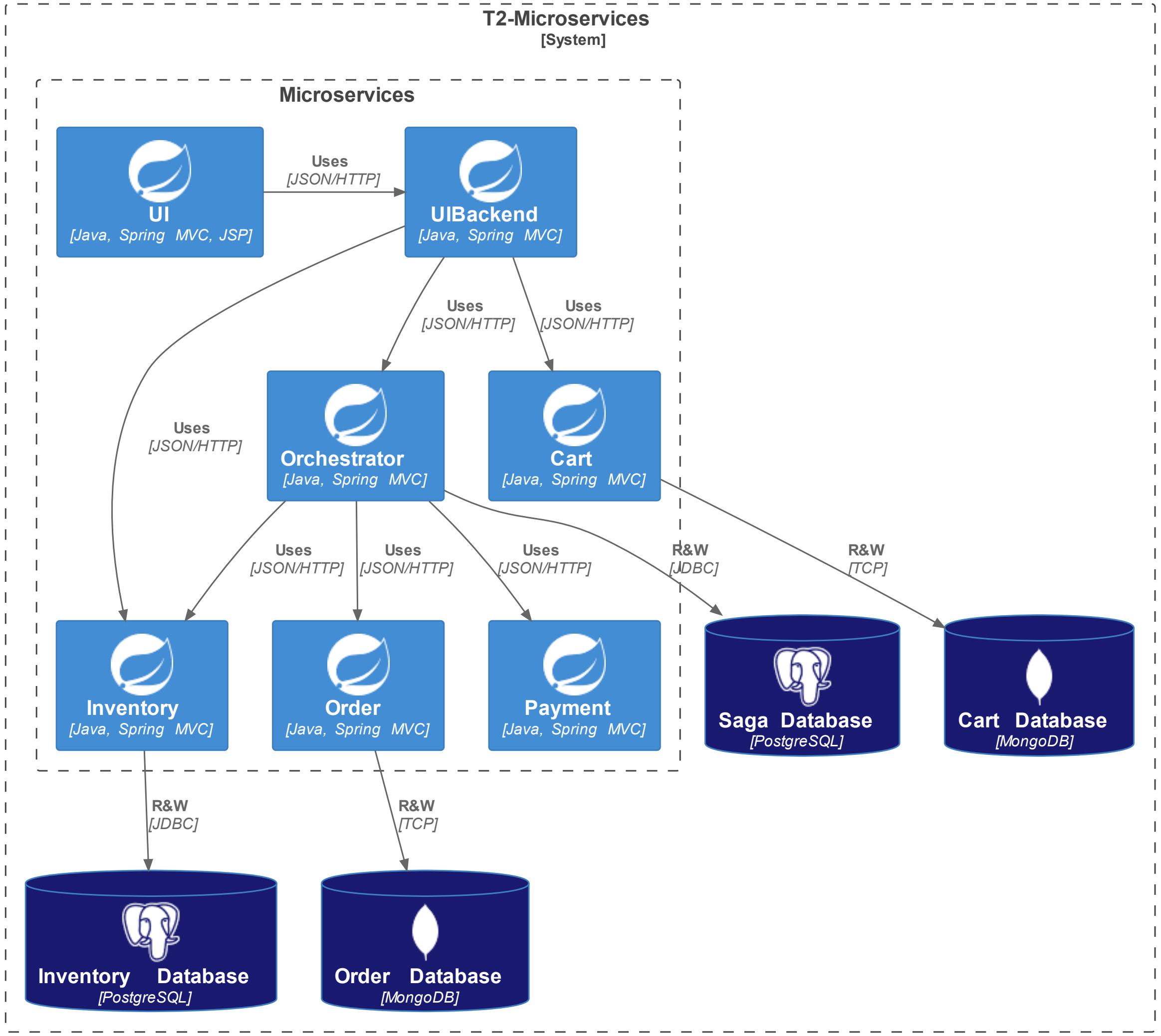
Reference Application – T2-Project

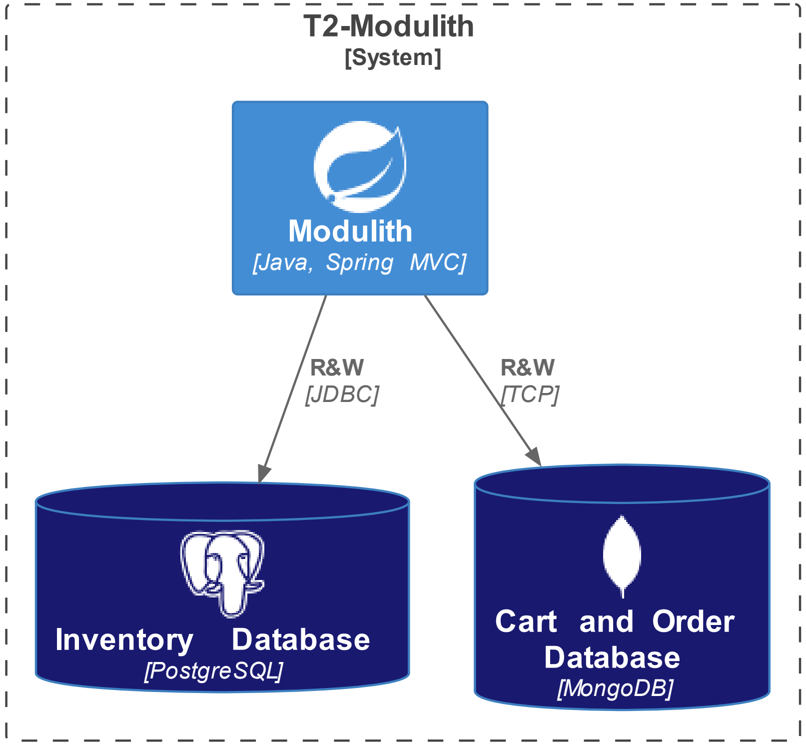
Business & System Context



Reference Application – T2-Project

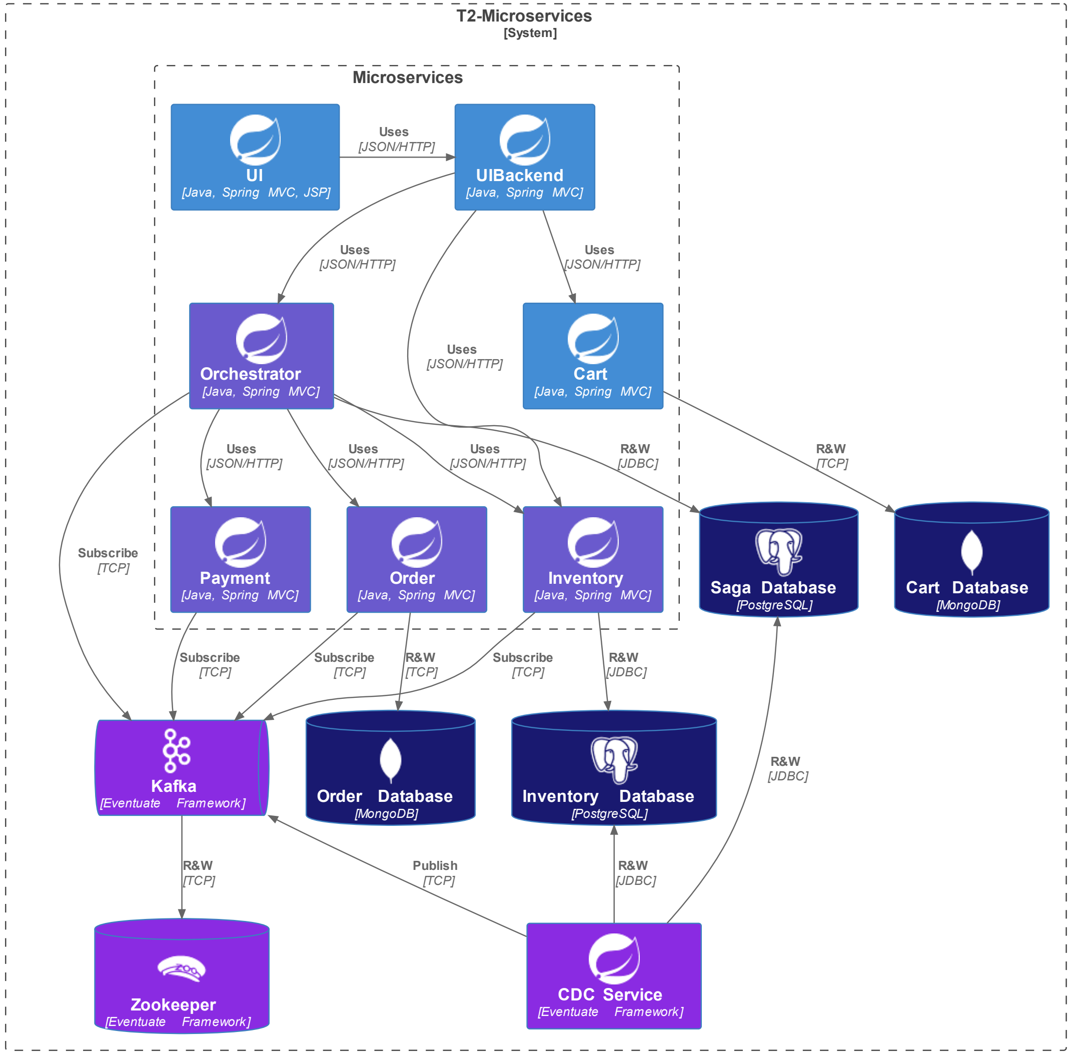
Variants: T2-Microservices & T2-Modulith

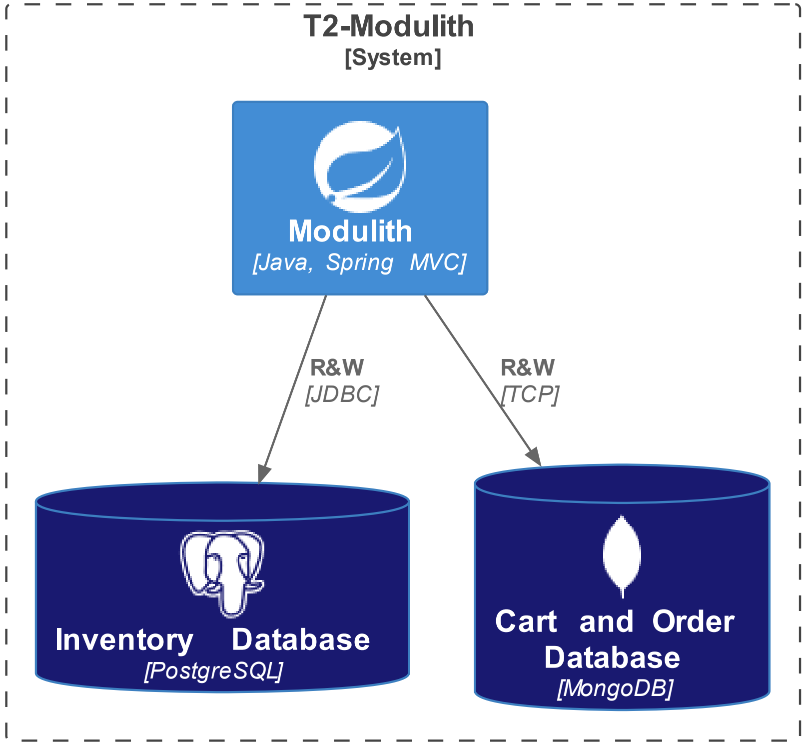




Reference Application – T2-Project

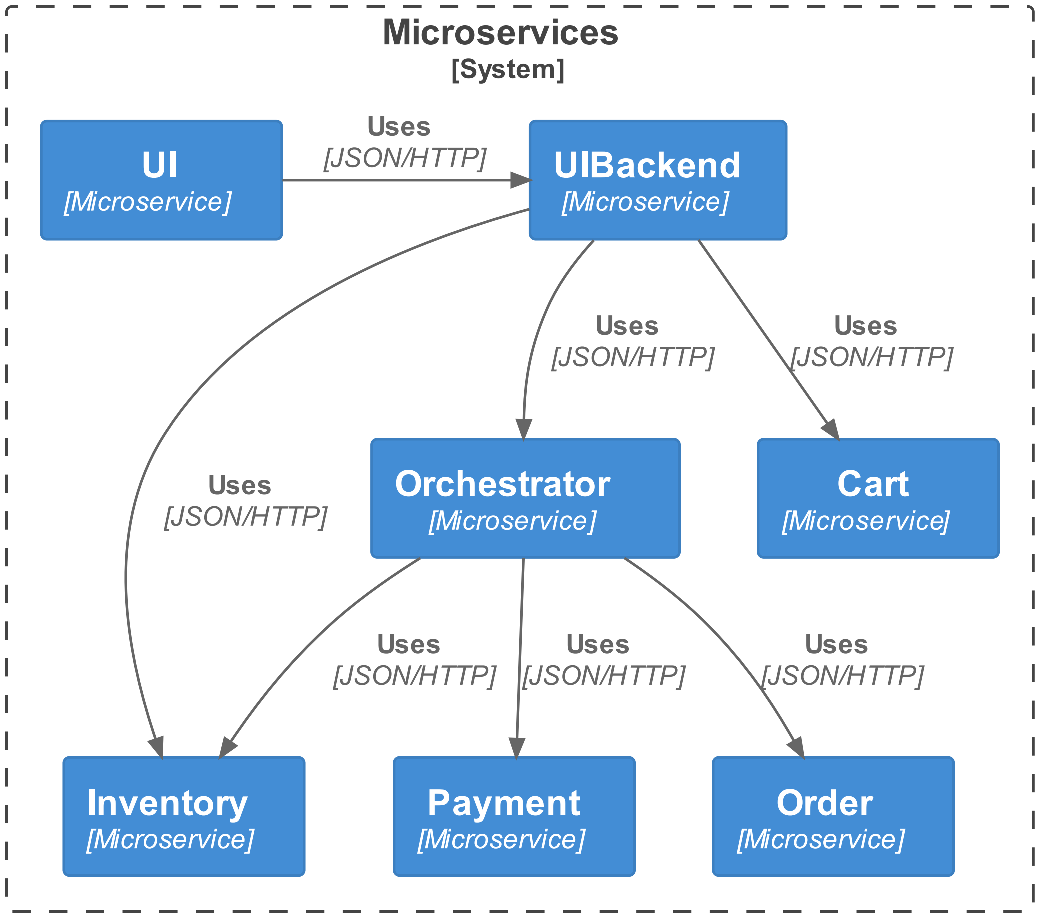
Implementation of the Saga Pattern & Messaging Middleware

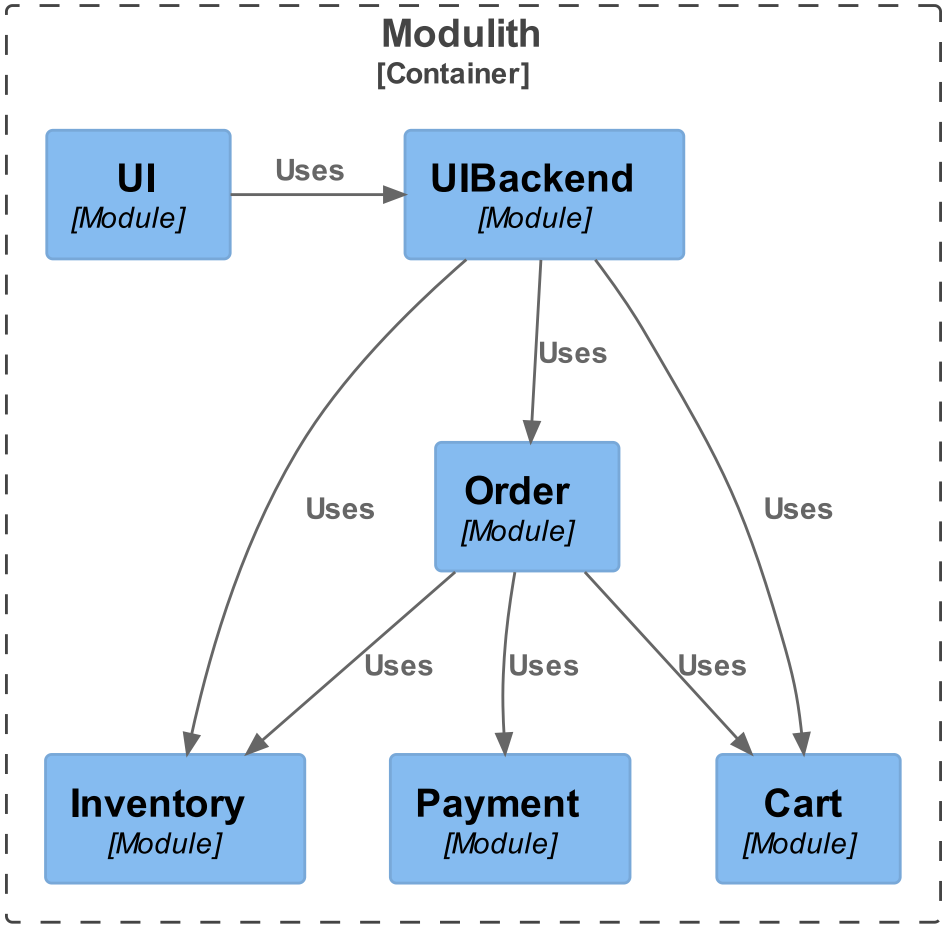




Reference Application – T2-Project

Modularity

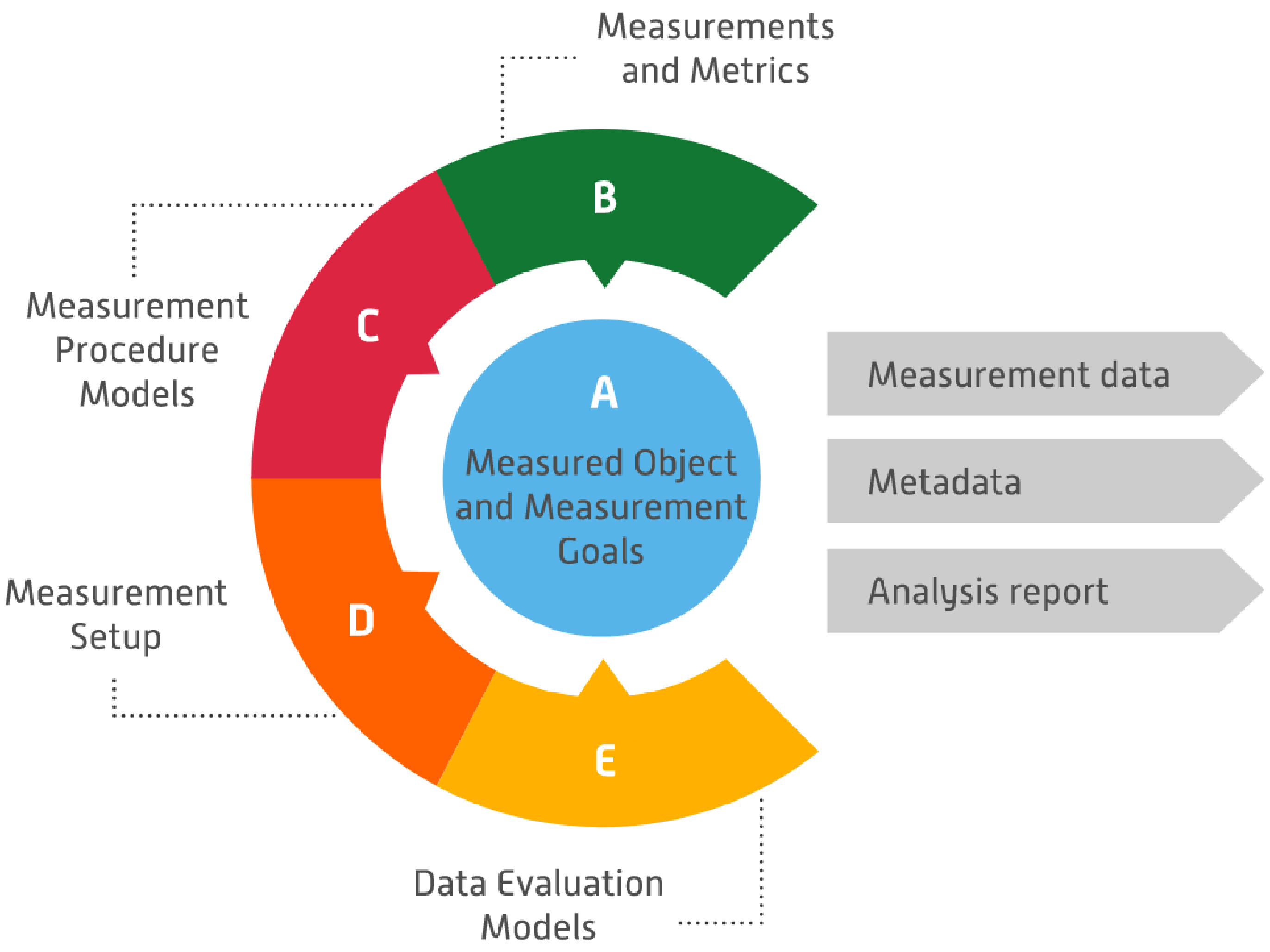




Measurement Methodology

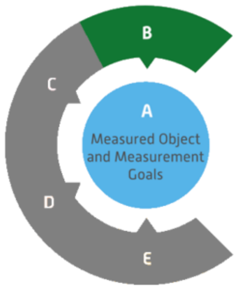
Measurement Methodology

Green Software Measurement Model (GSMM) by Guldner et al. (2024)



[GBC+24]

Measurement Model – Measurements & Metrics



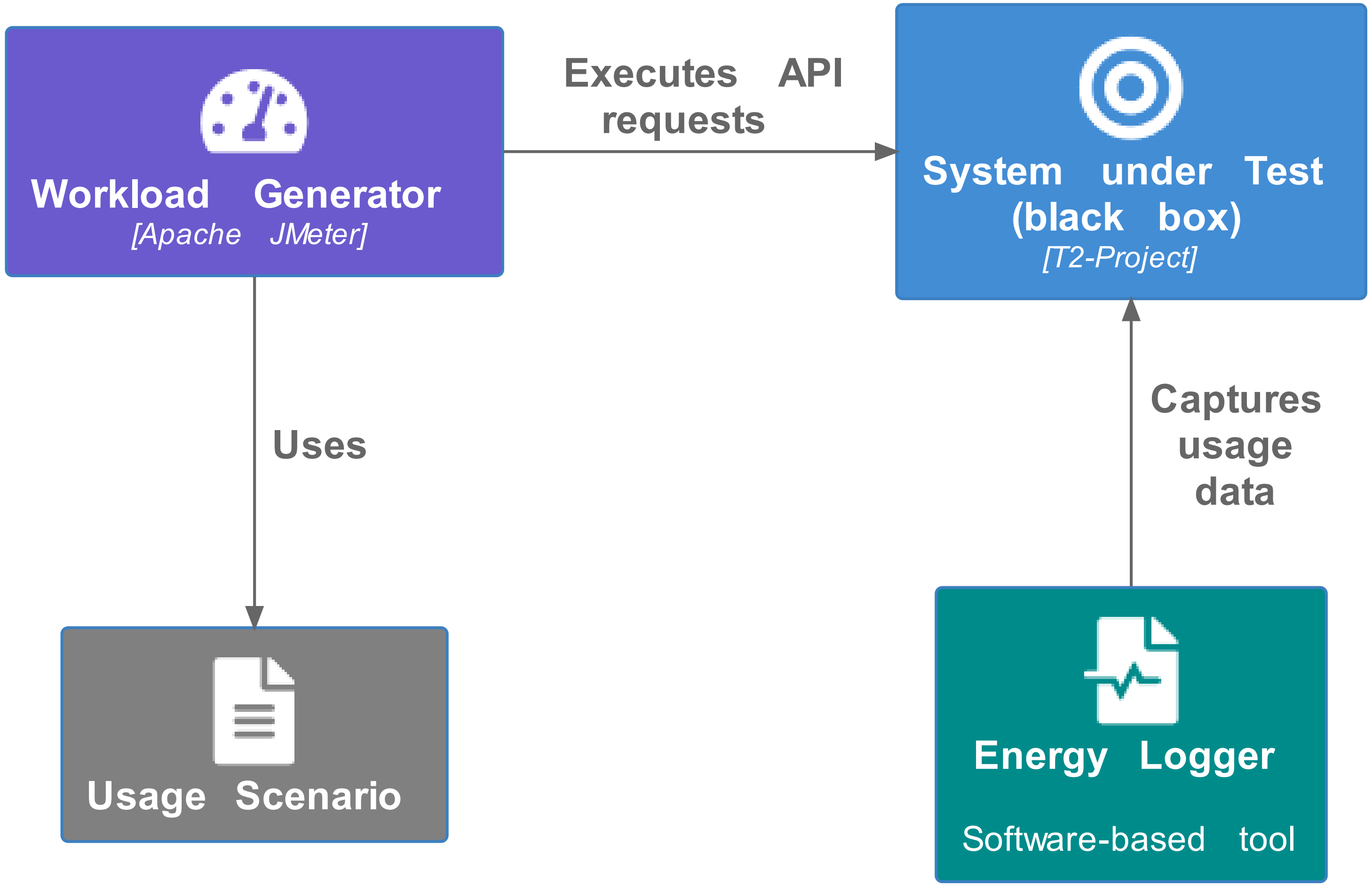
- Metric (“useful work”): Energy consumption of one order
- Measurement: Processing of three sequential HTTP requests

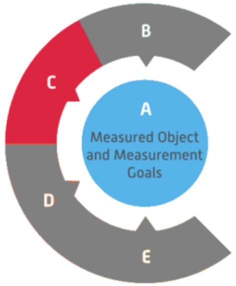
GET
product list

POST
add item to cart

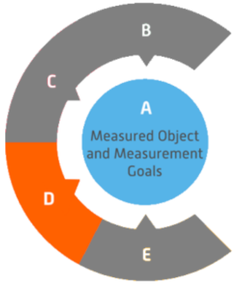
POST
confirm order

Measurement Model – Procedure





Measurement Model – Setups

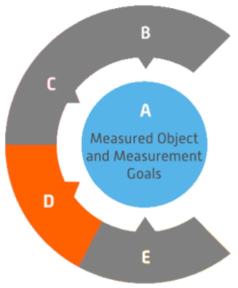


Green Metrics Tool

Kubernetes & Kepler

KEPLER

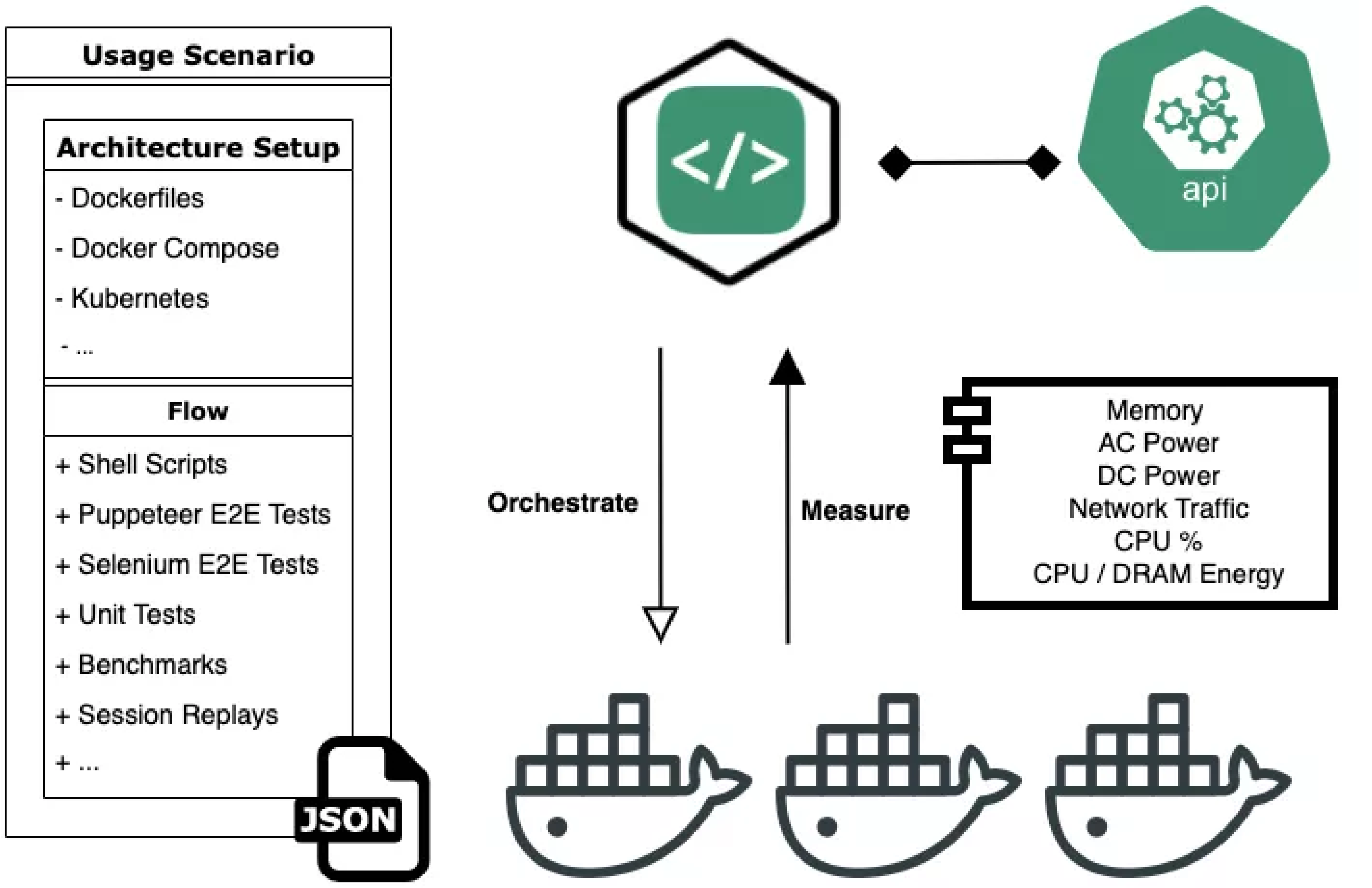
Measurement Setup 1



Green Metrics Tool

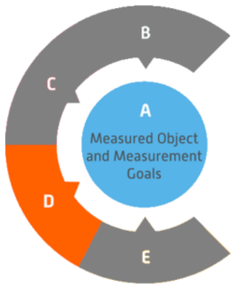
Green Metrics Tool

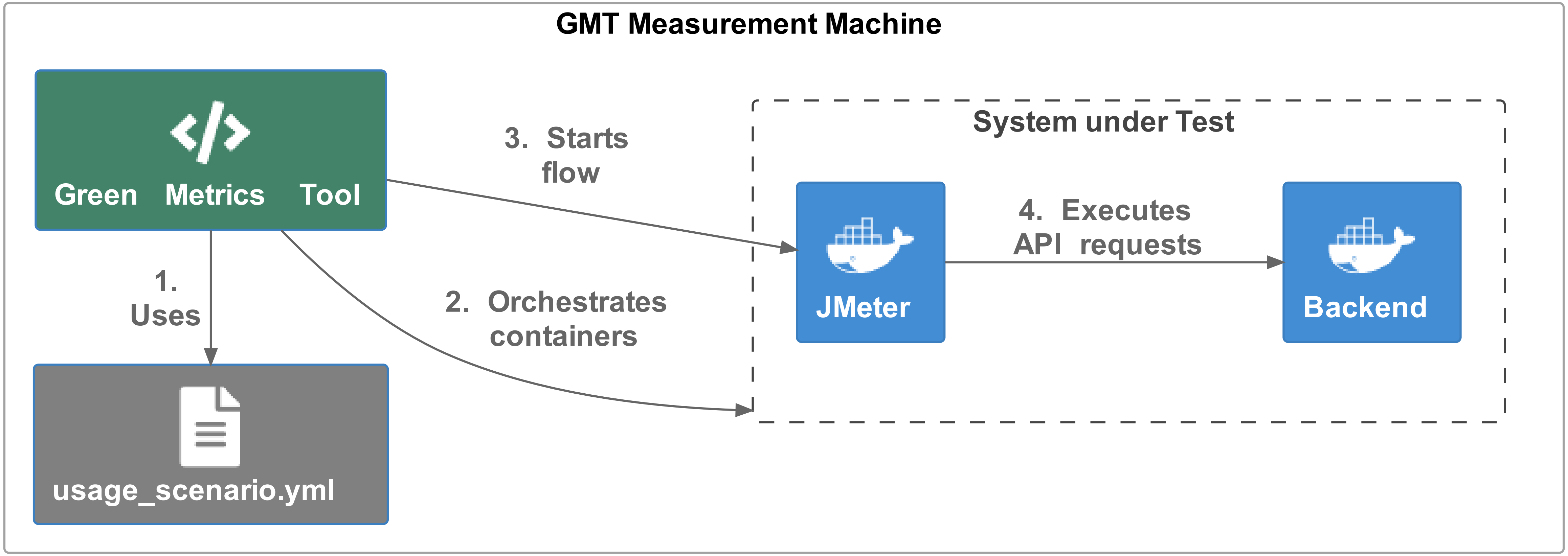
Main purpose: measure energy consumption of use case scenarios



Source: https://docs.green-coding.io/docs/prologue/measurement-process/

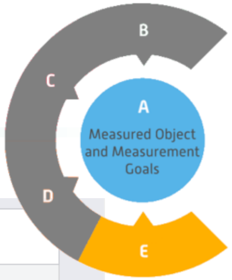
Measurement Setup 1: Green Metrics Tool

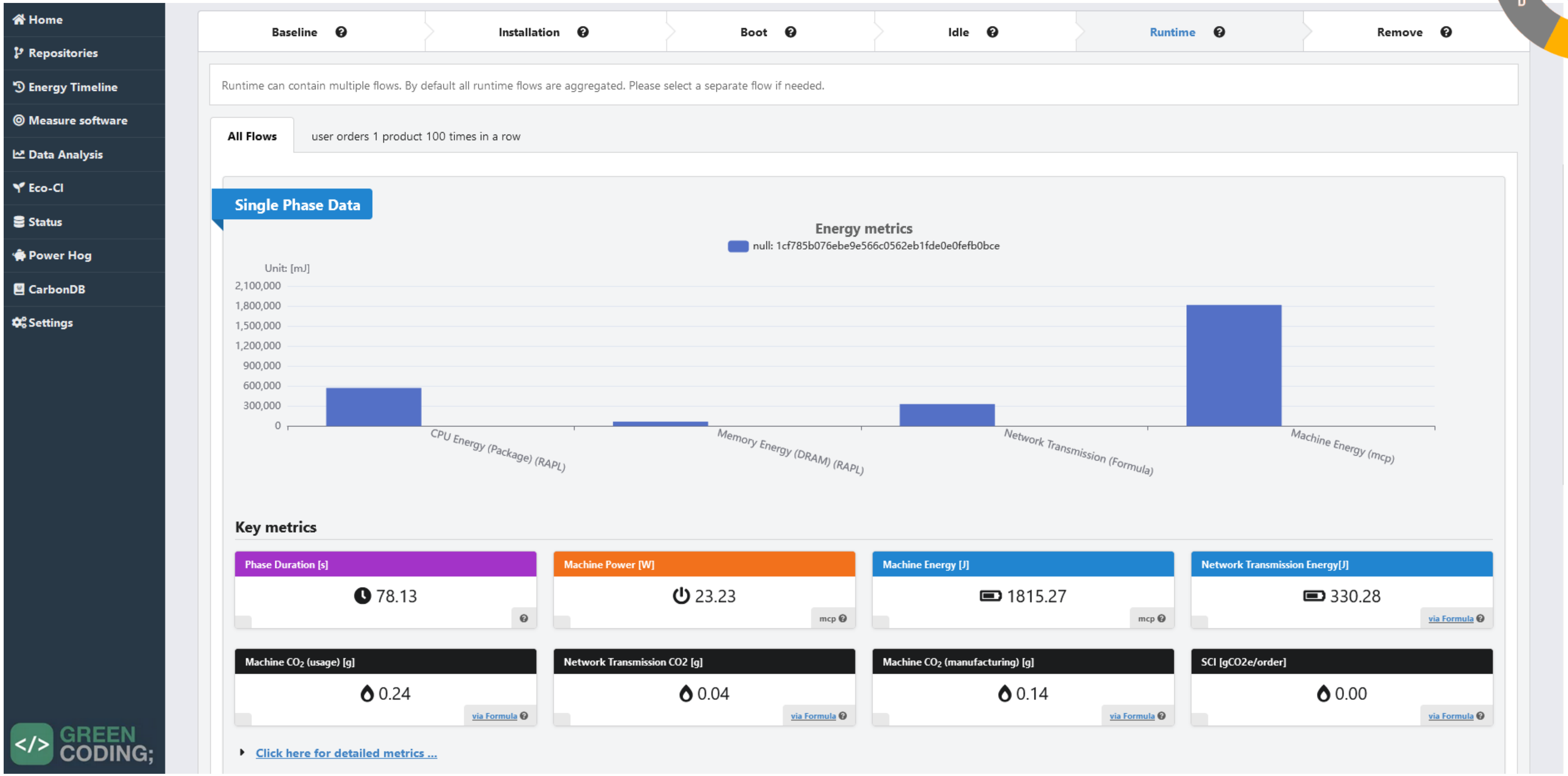




Green Metrics Tool – Data Evaluation

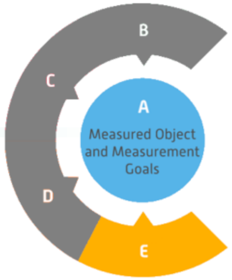
GMT Dashboard: Single Run View (Key Metrics)



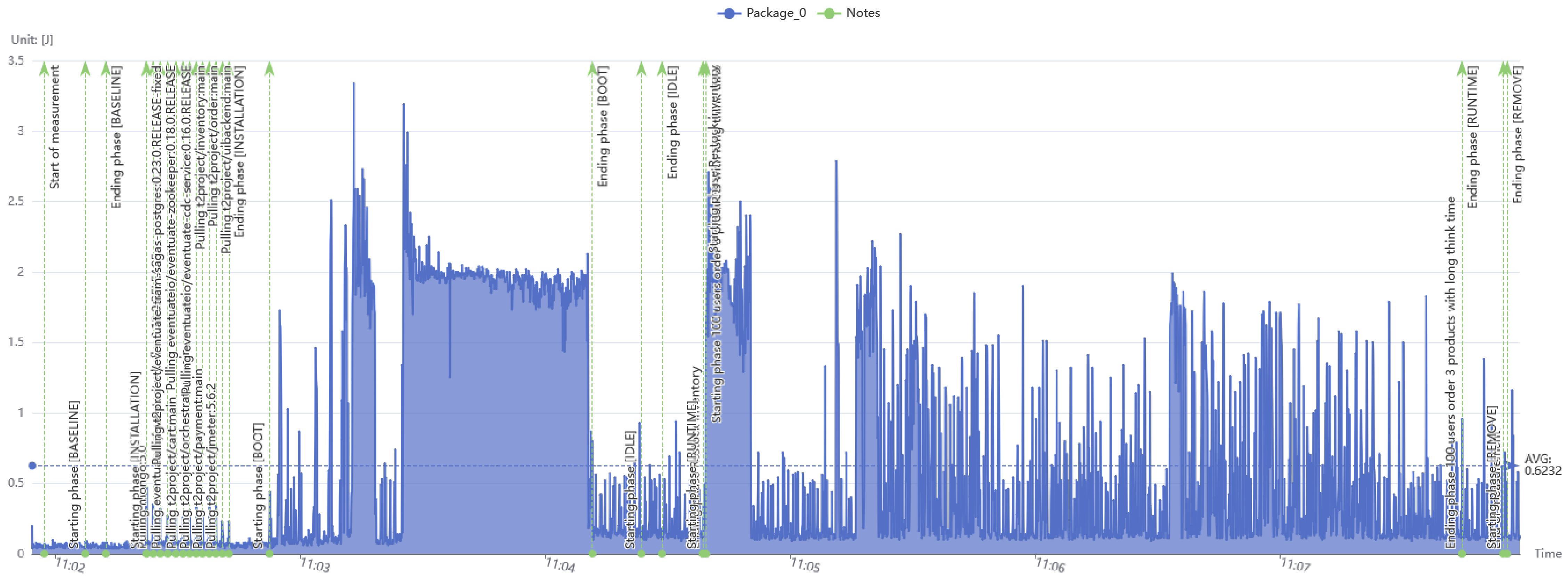


Green Metrics Tool – Data Evaluation

GMT Dashboard: CPU Energy Consumption

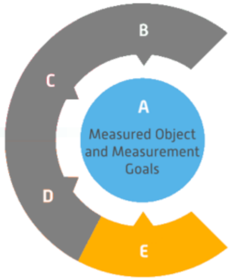


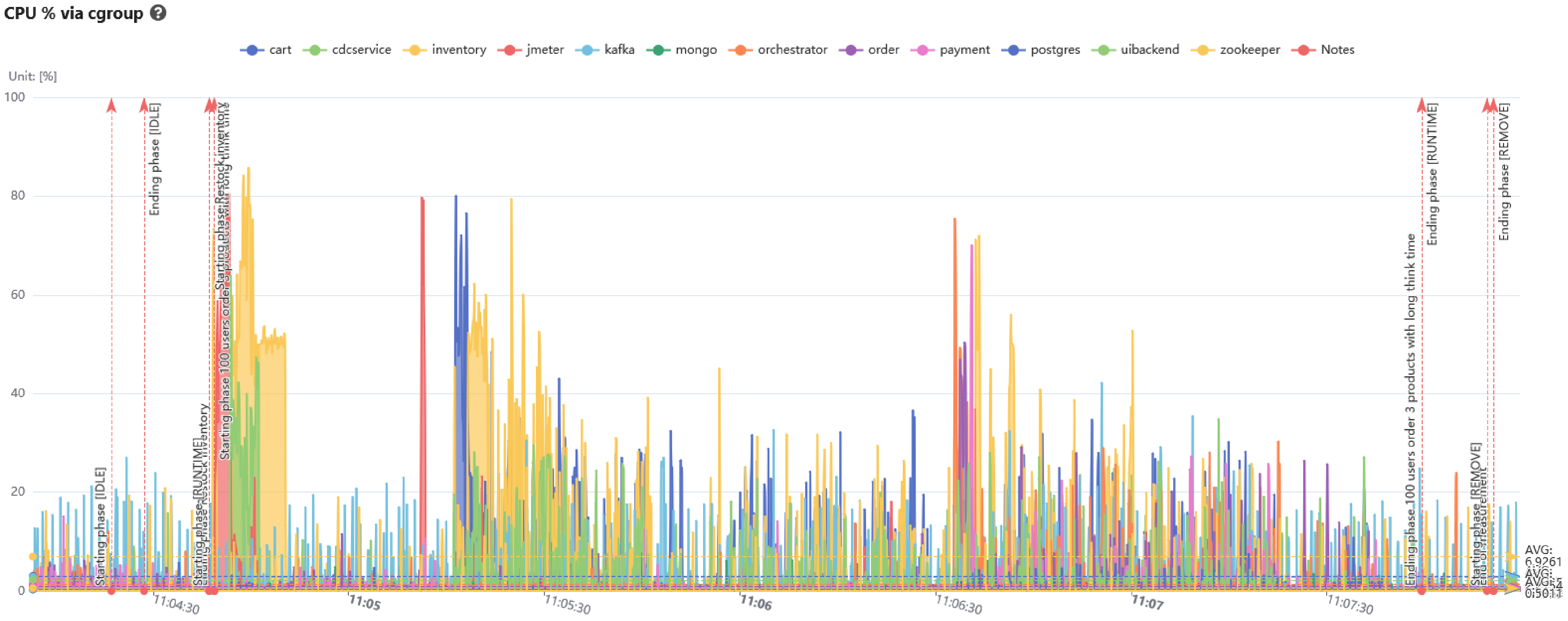
CPU Energy (Package) via RAPL



Green Metrics Tool – Data Evaluation

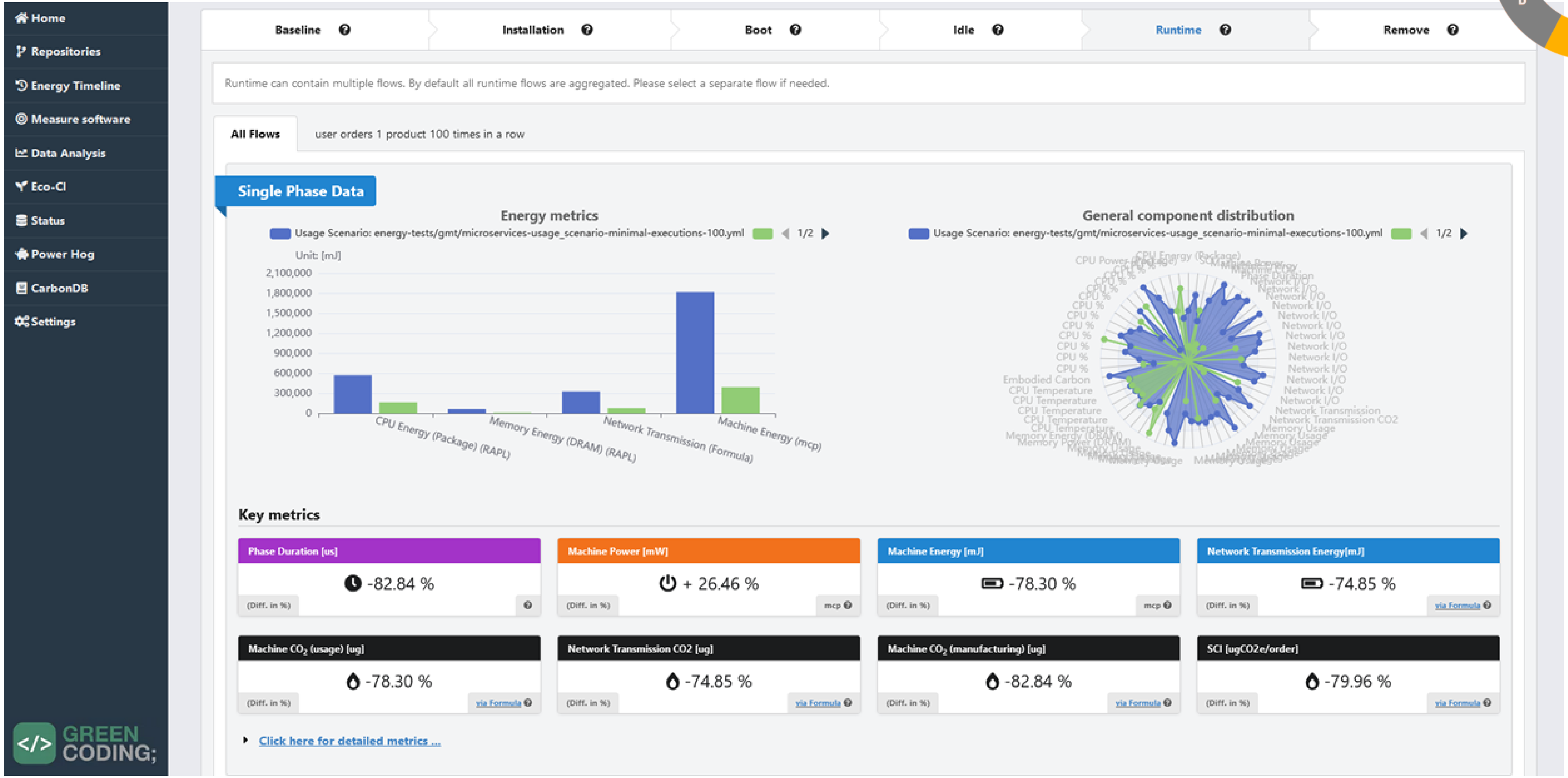
GMT Dashboard: CPU Utilization

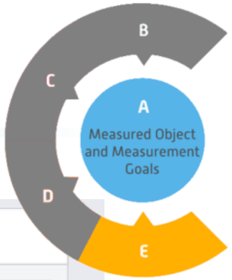




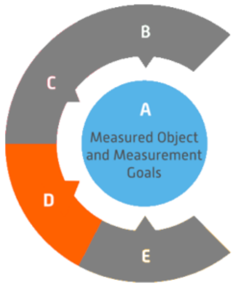
Green Metrics Tool – Data Evaluation

GMT Dashboard: Comparison View



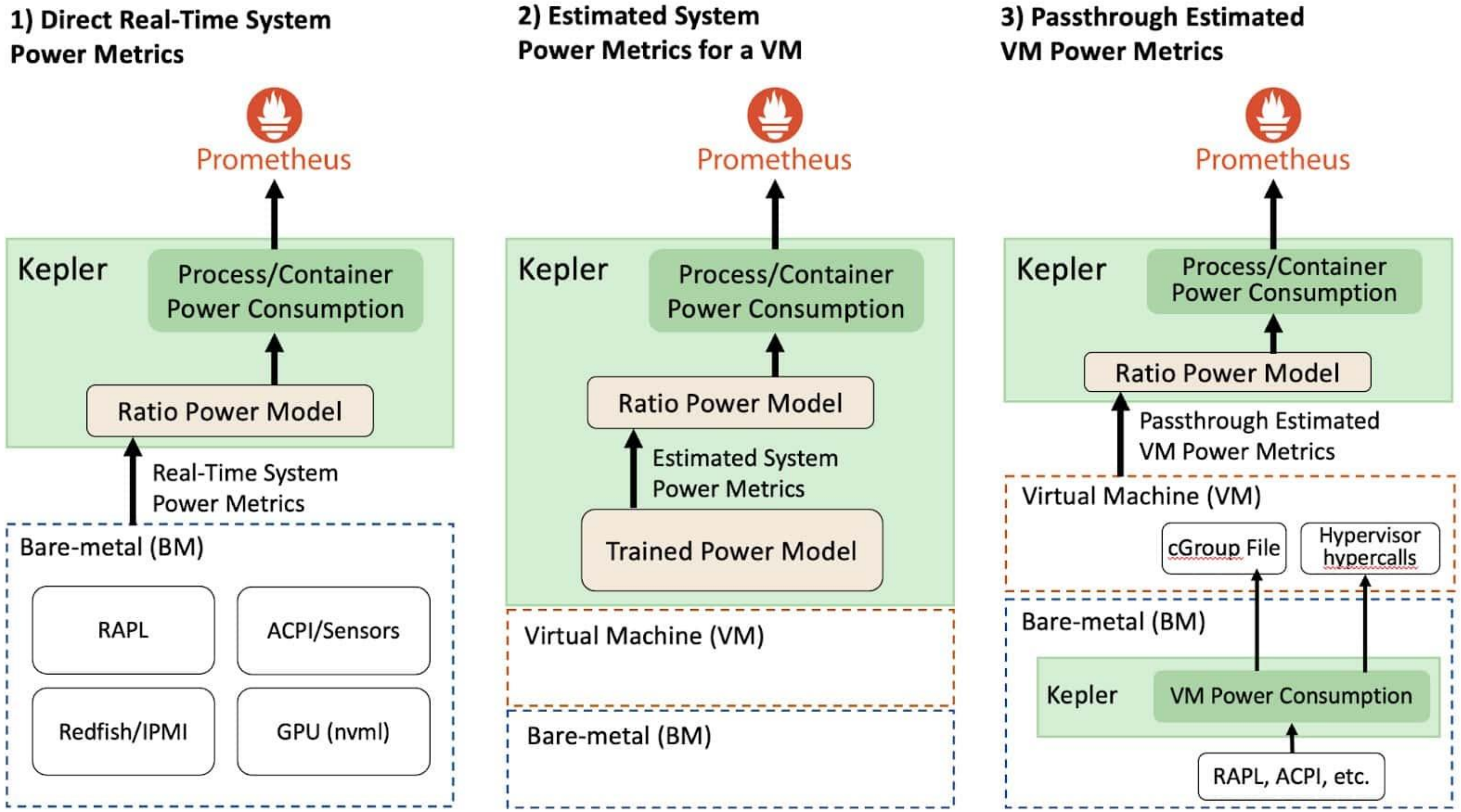


Measurement Setup 2



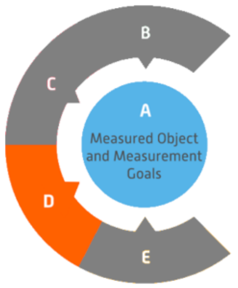
Kepler

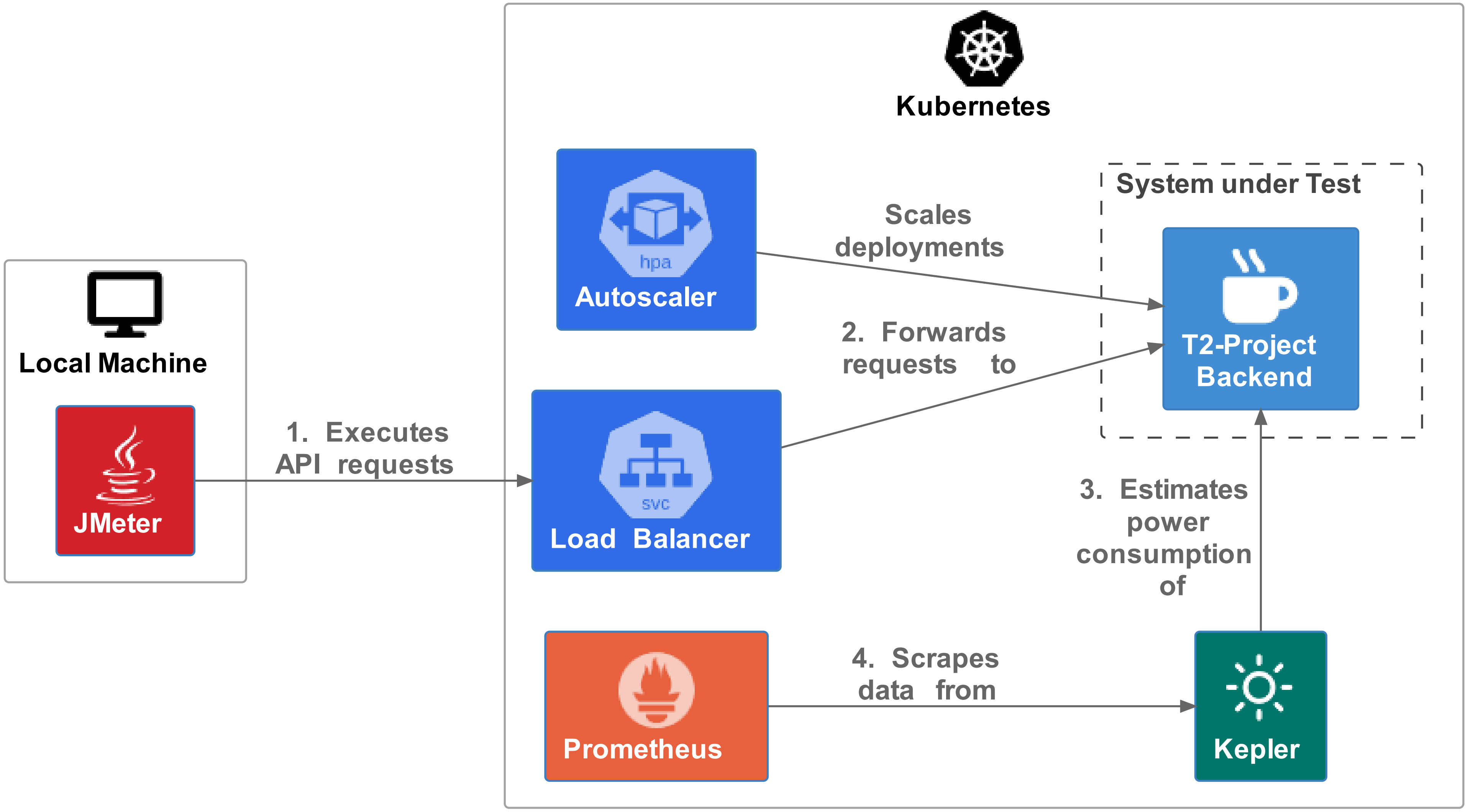
- “Kubernetes-based Efficient Power Level Exporter”
- Measures/estimates power consumption of containers in real-time



Source: https://sustainable-computing.io/usage/deep_dive/

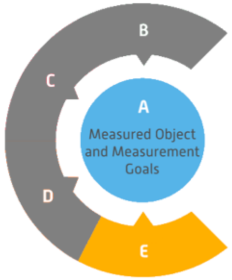
Measurement Setup 2: K8s & Kepler

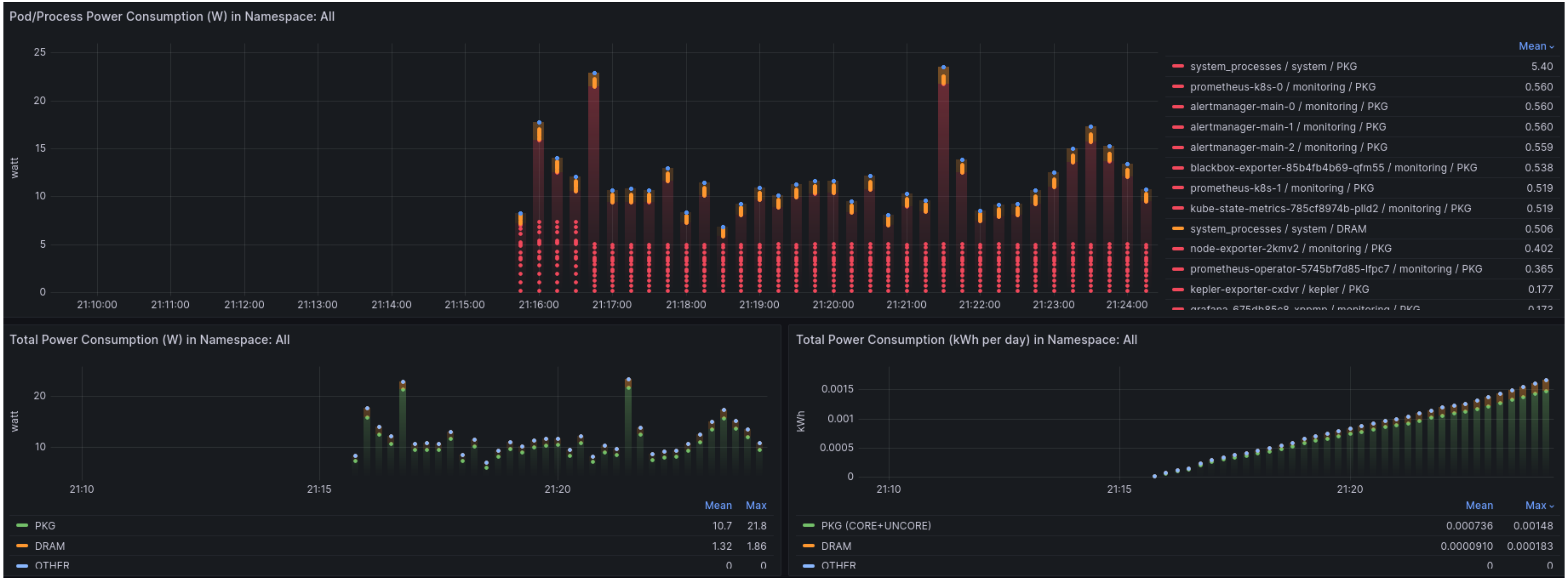




Measurement with Kepler – Data Evaluation

Grafana Dashboard

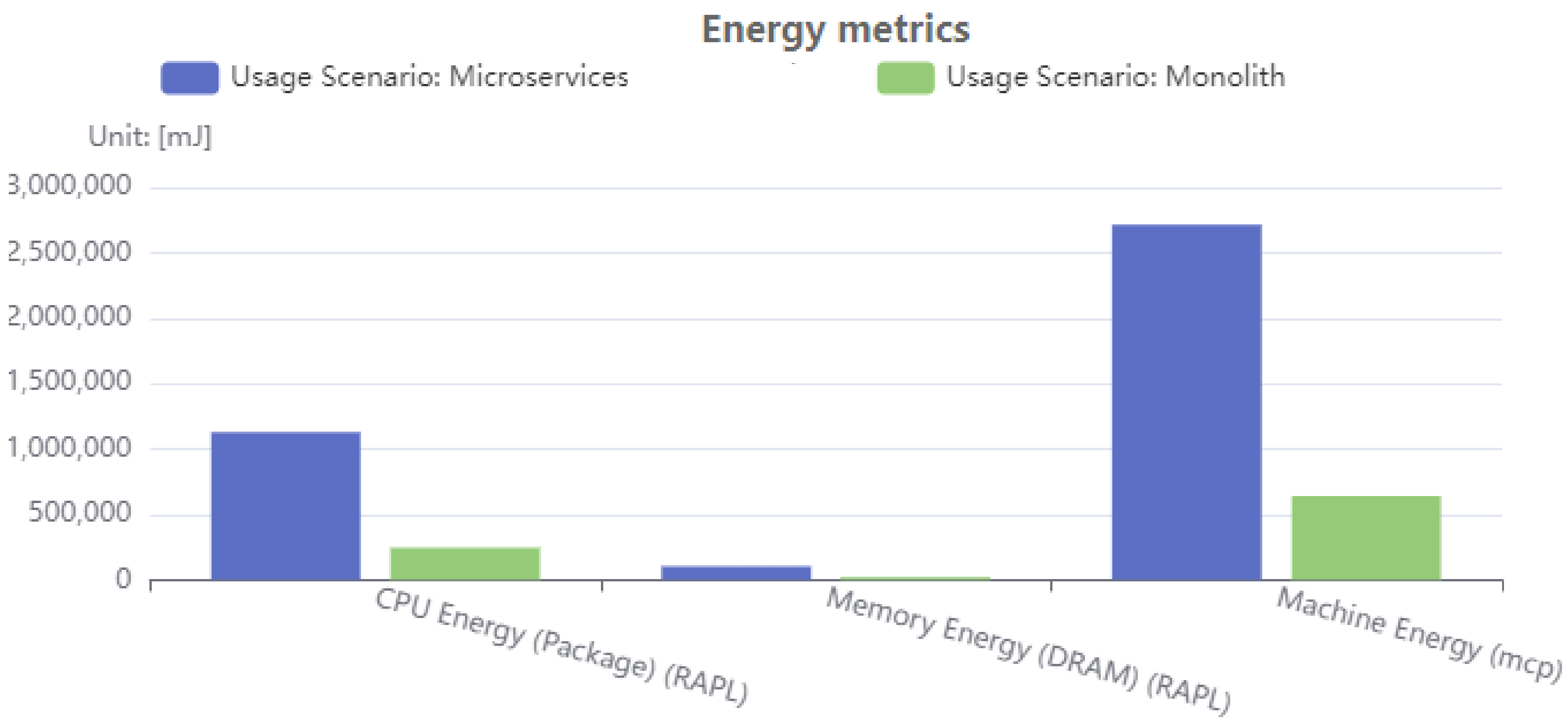


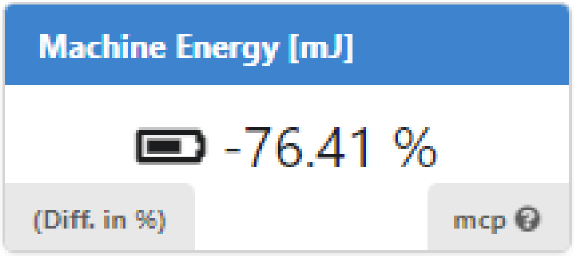


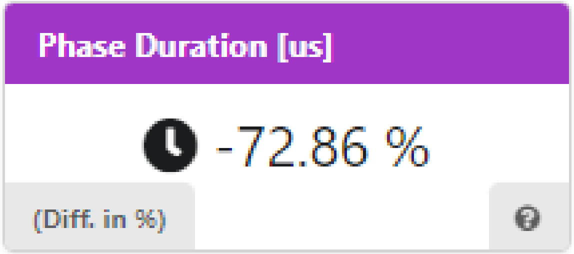
Results & Discussion

Results – Green Metrics Tool

Energy Consumption of Boot Phase

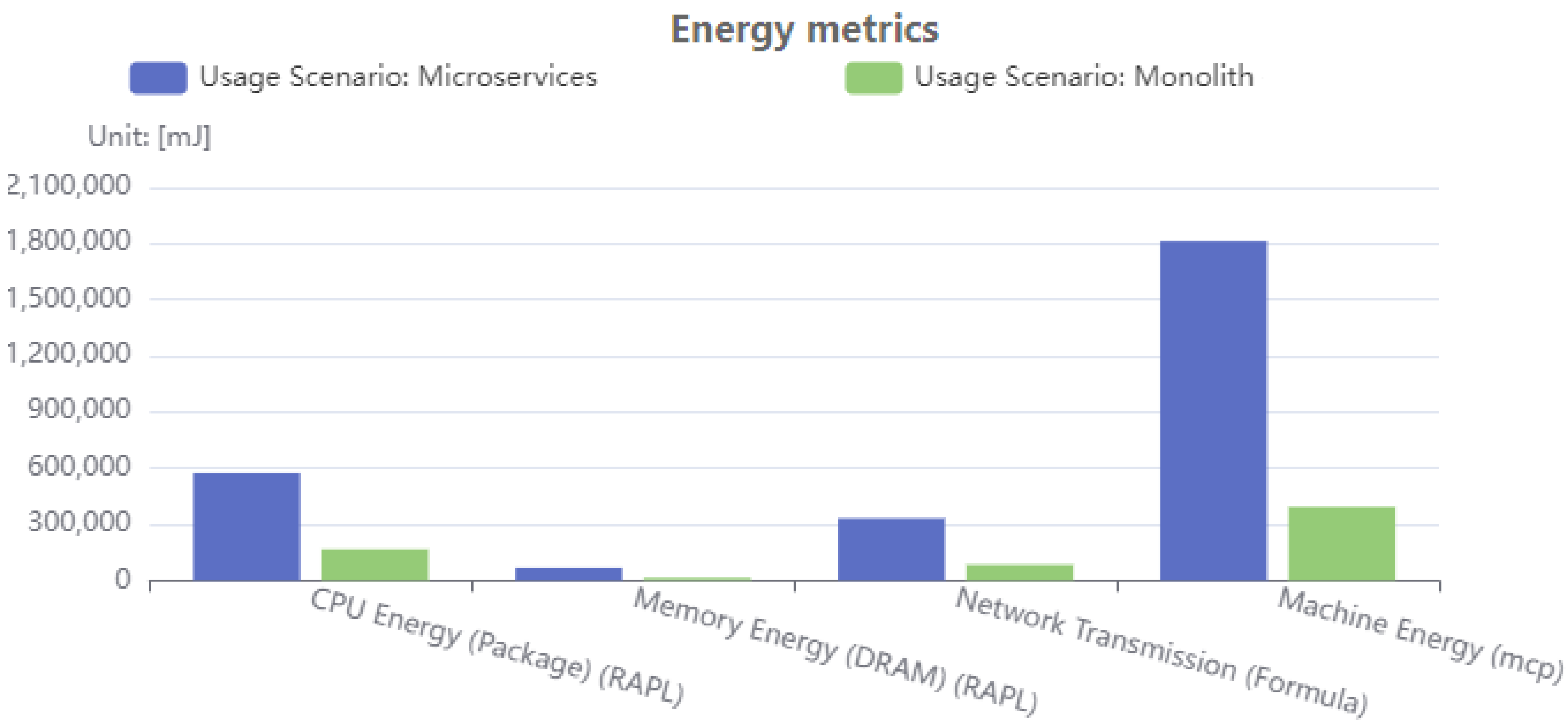


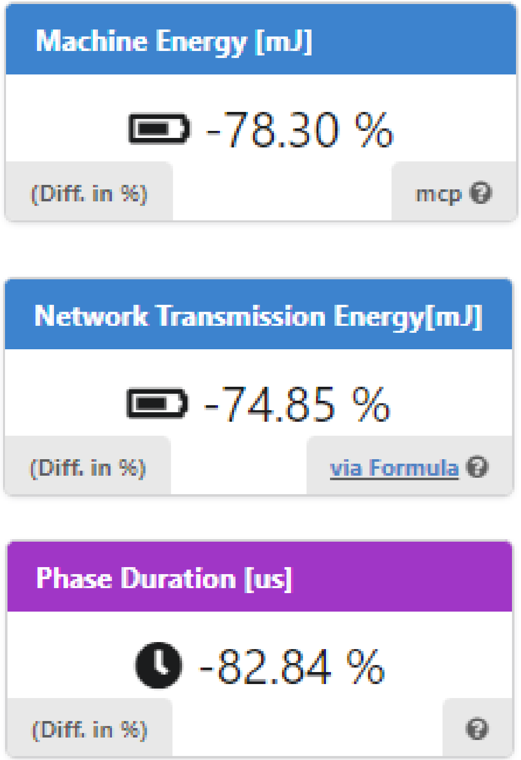




Results – Green Metrics Tool

Scenario: 100 Sequential Executions

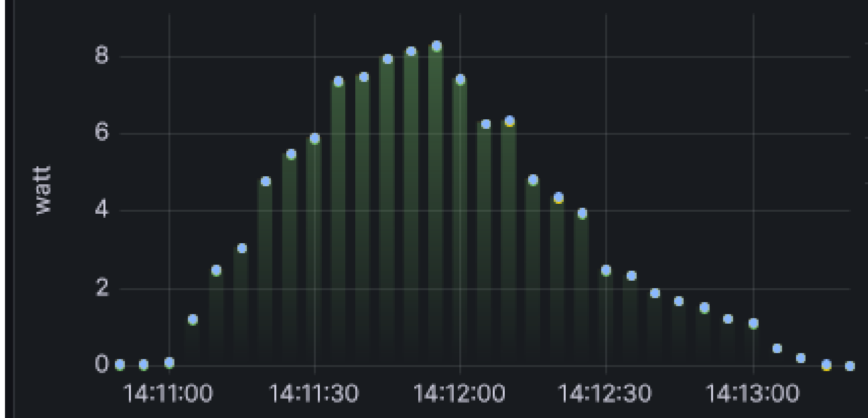




Results – K8s & Kepler

Scenario: 1 user, 100 executions (no scaling)

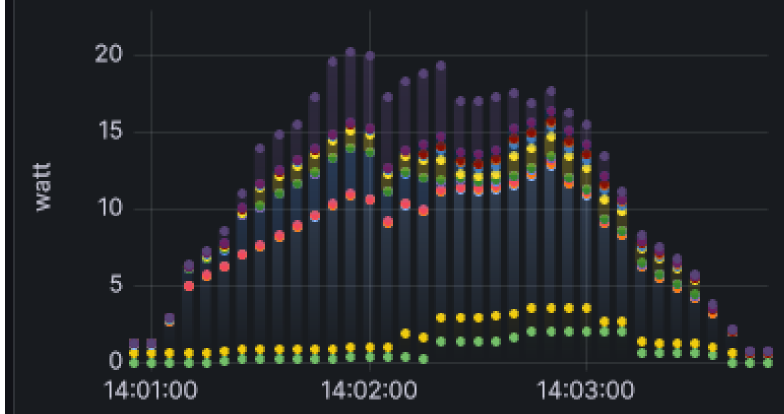
"t2-modulith" – Pod Power Consumption (W)



Name	Mean	Max	Total
backend-5798b44c5c-d2pqp	3.47	8.24	108
mongo-mongodb-6d878fcbdc-pjcdj	0.0216	0.0436	0.671
postgres-0	0.00581	0.0109	0.180

Energy Consumption (Ws / J)

"t2-microservices" – Pod Power Consumption (W)



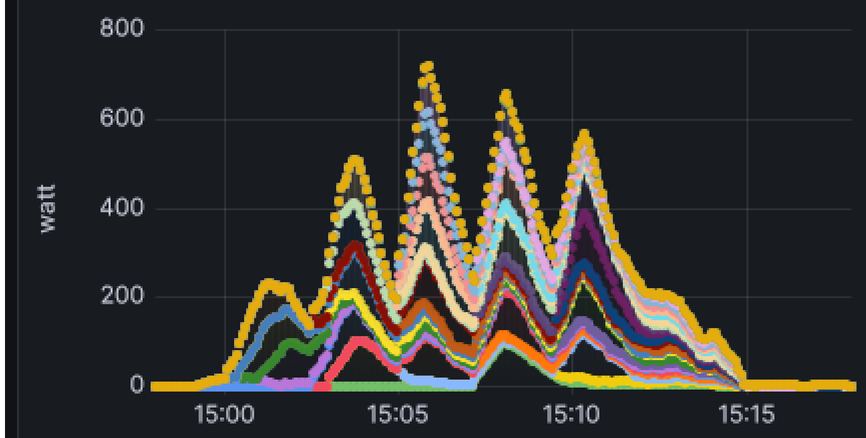
Name	Mean	Max	Total
inventory-744d446954-8cm42	5.96	9.93	215
uibackend-6896c76b89-s68bt	1.81	4.66	65.2
kafka-2	0.935	2.99	33.7
cdcservice-7dc8cd8df7-gss9d	0.899	1.57	32.4
orchestrator-65f9f5c5f7-vm886	0.761	1.39	27.4
cart-5f945cf68-j9gv2	0.737	2.08	26.5
order-6df8b6654f-dgfqs	0.280	0.656	10.1
postgres-orchestrator-0	0.234	0.624	8.43

Energy Consumption (Ws / J)

Results – K8s & Kepler

Scenario: 50 users, 10 min ramp-up, 5 min hold

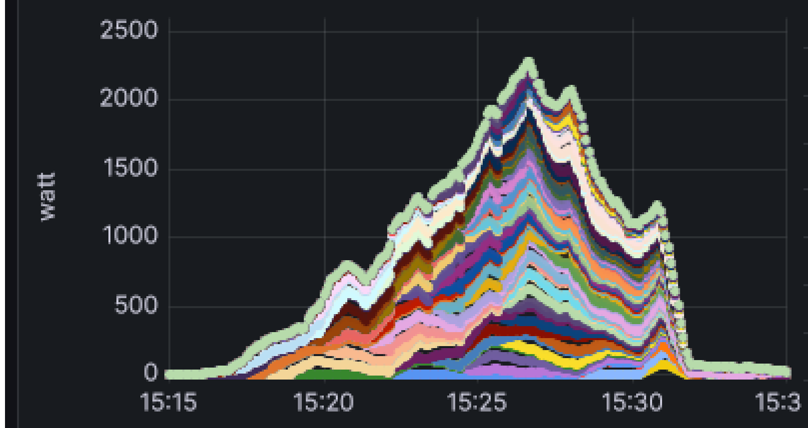
"t2-modulith" – Pod Power Consumption (W)



Name	Mean	Max	Total
backend-76674b8bb7-r8tnq	23.0	108	2345
backend-76674b8bb7-rc7n2	22.6	105	2240
backend-76674b8bb7-xjzv4	19.9	109	2588
backend-76674b8bb7-6hwpg	19.8	99.6	2040
backend-76674b8bb7-s5csp	19.7	105	2560
backend-76674b8bb7-ckchw	19.6	99.3	1936
backend-76674b8bb7-l8ct8	18.5	107	2911
backend-76674b8bb7-v4fd8	18.0	107	2827

Energy Consumption (Ws / J)

"t2-microservices" – Pod Power Consumption (W)



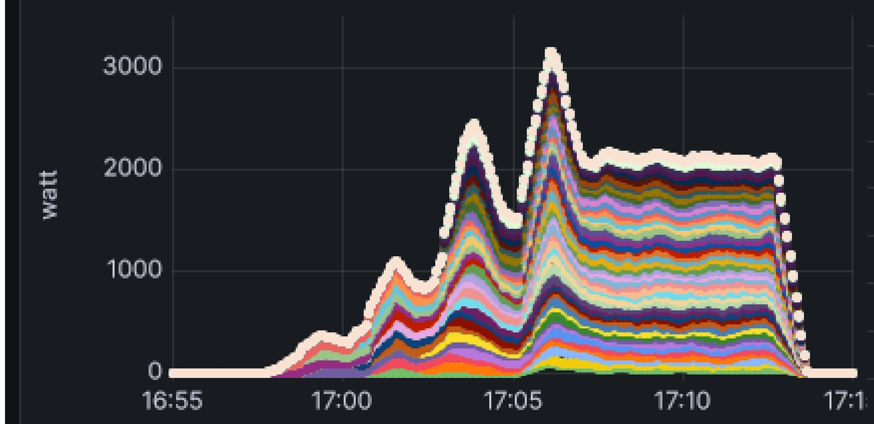
Name	Mean	Max	Total
inventory-7d9b5b5478-f7xcr	46.1	107	7558
inventory-7d9b5b5478-scntr	36.8	107	4126
inventory-7d9b5b5478-fr62r	35.8	106	3470
inventory-7d9b5b5478-v5dhb	33.9	109	6128
inventory-7d9b5b5478-l4jpz	33.5	98.9	3254
inventory-7d9b5b5478-98sfw	32.4	107	3631
inventory-7d9b5b5478-4w996	32.4	106	4116
inventory-7d9b5b5478-vwsdr	32.4	105	3142

Energy Consumption (Ws / J)

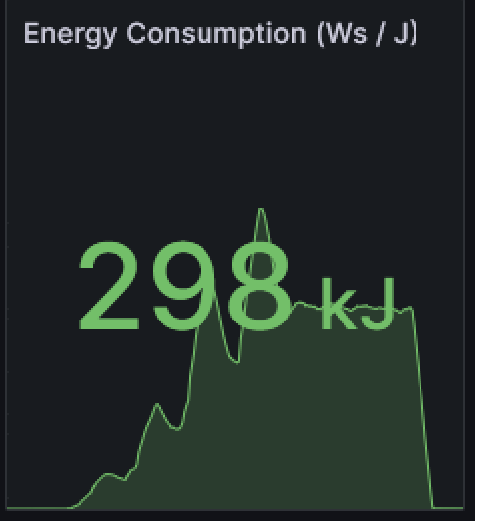
Results – K8s & Kepler

Scenario: Compute-intensive (~1 sec per order), 50 users, 10 min ramp-up, 5 min hold

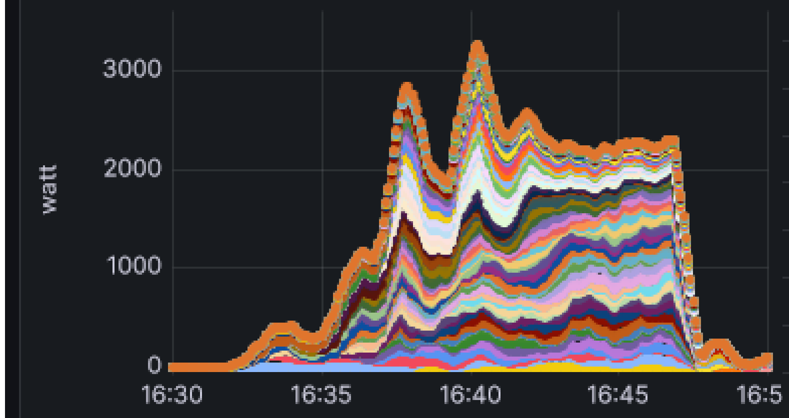
"t2-modulith" – Pod Power Consumption (W)



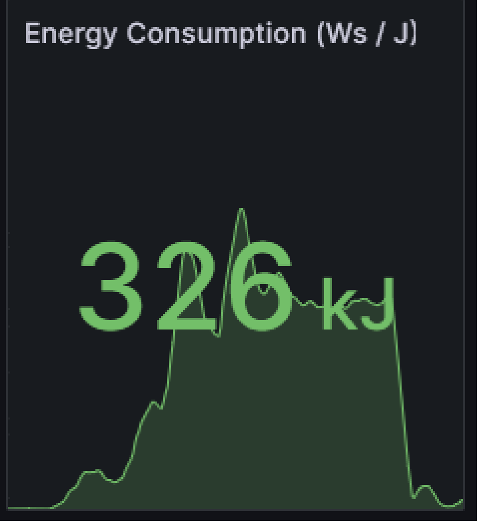
Name	Mean	Max	Total
backend-5c76ddbcf8-nlf2k	47.9	92.3	9386
backend-5c76ddbcf8-n9bjx	45.6	104	5380
backend-5c76ddbcf8-vkl5l	45.3	105	5207
backend-5c76ddbcf8-lr84d	45.3	105	5340
backend-5c76ddbcf8-gcbzx	45.1	103	5324
backend-5c76ddbcf8-6fm5x	44.7	101	6885
backend-5c76ddbcf8-6fz9t	44.4	104	7640
backend-5c76ddbcf8-wlzz9	44.4	98.2	6348



"t2-microservices" – Pod Power Consumption (W)



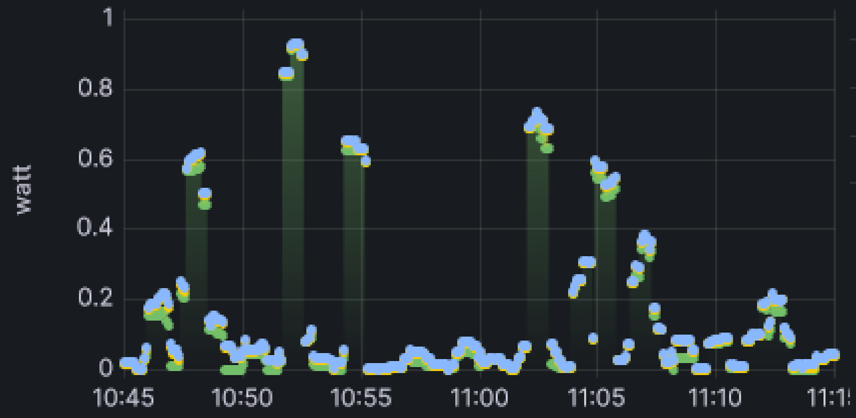
Name	Mean	Max	Total
computation-simulator-754444d565-g5wrg	53.1	111	8132
computation-simulator-754444d565-9d7bw	48.9	109	7631
computation-simulator-754444d565-4l4b4	45.9	110	6608
computation-simulator-754444d565-6v67f	45.7	111	6587
computation-simulator-754444d565-56pbm	45.5	112	10965
computation-simulator-754444d565-k2kb4	43.9	110	7639
computation-simulator-754444d565-crgcv	43.0	103	7488
computation-simulator-754444d565-tvjwv	43.0	101	7524



Results – K8s & Kepler

Energy Consumption in Idle (30 min)

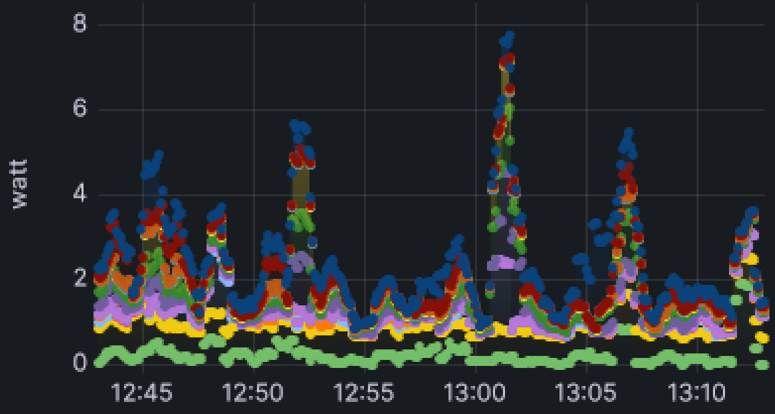
"t2-modulith" – Pod Power Consumption (W)



Name	Mean	Max	Total
backend-55dfcc4469-nvfvf	0.150	0.921	54.0
mongo-mongodb-6d878fcbdc-hzx27	0.0143	0.0665	5.17
postgres-0	0.00533	0.0109	1.93

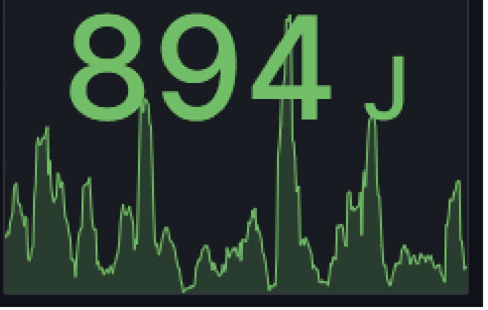
Energy Consumption (Ws / J)

"t2-microservices" – Pod Power Consumption (W)



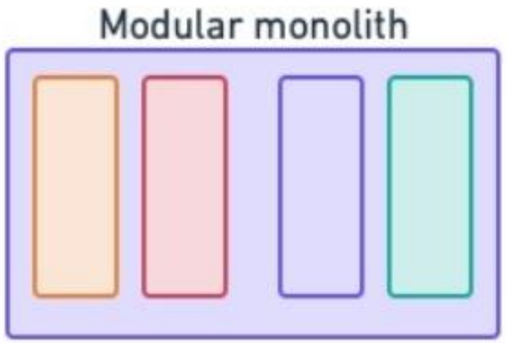
Name	Mean	Max	Total
cdcservice-667db4d459-br6bj	0.677	1.11	245
uibackend-6f5fff8787-4xmk7	0.341	2.47	123
inventory-6b86d657d-bnrbw	0.261	1.67	94.3
cart-67f676cc8-kdf29	0.261	1.90	94.2
order-59644875d7-jbxl8	0.248	1.52	89.4
payment-68cd944745-dwwdw	0.240	1.49	86.5
orchestrator-79869c9d55-z8wfr	0.226	2.12	81.5
ui-cc87d879b-bkb4l	0.136	0.818	49.0

Energy Consumption (Ws / J)



Discussion

Energy Efficiency – Modular Monolith vs. Microservices



➡️ No overhead through network communication

➡️ Only one runtime environment

➡️ Local transactions

➡️ Fain-grained scalability

➡️ Potential for better utilization of resources due to smaller size

➡️ Hibernate of individual components (not tested)

Symbols by [Fer22]

Learnings

GMT: Good for measuring usage scenarios and comparing different versions

Kepler: Good for monitoring workloads over longer time in K8s environments

Different philosophies of measurement tools:
Measurement/Estimation? Metrics provider? Per-process measurement? Virtualized environments?

Energy consumption of network transfer? Quantification is challenging

Saga is quite slow and inefficient (but ensures data integrity and scalability)

Conclusions

Modular Monolith is easier to handle than a microservices system

Monoliths are more energy efficient in scenarios with low or constant load

Microservices have advantages in compute-intensive scenarios with high load

There is no general recommendation, it depends on your scalability needs envite consulting GmbH

www.envite.de

Questions?

Energieeffizienz von Backend-Architekturen

David Kopp

david.kopp@envite.de

linkedin.com/in/david-kopp-70a609248

envite

References for Related Work

- Ueda, T., Nakaike, T., & Ohara, M. (2016). Workload characterization for microservices. *2016 IEEE International Symposium on Workload Characterization (IISWC)*, 1–10. https://doi.org/10.1109/IISWC.2016.7581269
- Villamizar, M., Garcés, O., Ochoa, L., Castro, H., Salamanca, L., Verano, M., Casallas, R., Gil, S., Valencia, C., Zambrano, A., & Lang, M. (2017). Cost comparison of running web applications in the cloud using monolithic, microservice, and AWS Lambda architectures. *Service Oriented Computing and Applications*, *11*(2), 233–247. https://doi.org/10.1007/s11761-017-0208-y
- Al-Debagy, O., & Martinek, P. (2018). A Comparative Review of Microservices and Monolithic Architectures. *2018 IEEE 18th International Symposium on Computational Intelligence and Informatics (CINTI)*, 000149–000154. https://doi.org/10.1109/CINTI.2018.8928192
- Bjørndal, N., Bucchiarone, A., Mazzara, M., Dragoni, N., & Dustdar, S. (2020). *Migration from monolith to microservices: Benchmarking a case study*. https://doi.org/10.13140/RG.2.2.27715.14883
- Blinowski, G., Ojdowska, A., & Przybylek, A. (2022). Monolithic vs. Microservice Architecture: A Performance and Scalability Evaluation. *IEEE Access*, *10*, 20357–20374. https://doi.org/10.1109/ACCESS.2022.3152803
- Okrój, S., & Jatkiewicz, P. (2023). Differences in performance, scalability, and cost of using microservice and monolithic architecture. *Proceedings of the 38th ACM/SIGAPP Symposium on Applied Computing*, 1038–1041. https://doi.org/10.1145/3555776.3578725
- Faustino, D., Gonçalves, N., Portela, M., & Rito Silva, A. (2024). Stepwise migration of a monolith to a microservice architecture: Performance and migration effort evaluation. *Performance Evaluation*, *164*, 102411. https://doi.org/10.1016/j.peva.2024.102411

Summary of results: Related Work

References

- [BHR19] Barroso, L. A., Hölzle, U., & Ranganathan, P. (2019). *The Datacenter as a Computer: Designing Warehouse-Scale Machines*. Springer International Publishing. https://doi.org/10.1007/978-3-031-01761-2
- [Bro18] S. Brown. “Modular Monoliths”. Conference Talk. GOTO 2018 (Berlin). Nov. 22, 2018. url: https://youtu.be/5OjqD-ow8GE
- [FBW+21] Freitag, C., Berners-Lee, M., Widdicks, K., Knowles, B., Blair, G. S., & Friday, A. (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations. Patterns, 2(9), 100340. https://doi.org/10.1016/j.patter.2021.100340
- [Fer22] Tomas Fernandez (2022). When Microservices Are a Bad Idea. https://semaphoreci.com/blog/bad-microservices
- [GBC+24] A. Guldner, R. Bender, C. Calero, G. S. Fernando, M. Funke, J. Gröger, L. M. Hilty, J. Hörnschemeyer, G.-D. Hoffmann, D. Junger, T. Kennes, S. Kreten, P. Lago, F. Mai, I. Malavolta, J. Murach, K. Obergöker, B. Schmidt, A. Tarara, J. P. De Veaugh-Geiss, S. Weber, M. Westing, V. Wohlgemuth, S. Naumann. “Development and Evaluation of a Reference Measurement Model for Assessing the Resource and Energy Efficiency of Software Products and Components—Green Software Measurement Model (GSMM)”. In: Future Generation Computer Systems 155 (June 1, 2024), pp. 402–418. doi: 10.1016/j.future.2024.01.033.
- [GSF22] Green Software Principles. https://learn.greensoftware.foundation/introduction
- [Haw24] Visualization “#ShowYourStripes”: Ed Hawkins (2024). CC BY 2.0. https://showyourstripes.info/s/europe/germany/stuttgart
- [IEA24] IEA (2024) Electricity 2024 - Analysis and forecast to 2026, IEA. https://www.iea.org/reports/electricity-2024
- [Sol17] Visualization “Monolith vs. Microservices vs. Serverless”: Jignesh Solanki (2017). https://dev.to/jignesh_simform/evolution-of-serverless-monolithic-microservices-faas-3hdp
- [Tag24] tagesschau (2024): Heißester Juni seit Aufzeichnungsbeginn. https://www.tagesschau.de/wissen/klima/klimaerwaermung-copernicus-100.html
- [Sti21] Stieß, S. S. (2021). Tracing the impact of SLO violations on business processes across a microservice architecture with the saga pattern [Master thesis]. https://doi.org/10.18419/opus-12038

Meetup Green Software Development Stuttgart

Nächste Termine:

- 5. September 18:00 – 20:00 Uhr
  - Ort: Syngenio (Wilhelmsplatz)
  - Thema: tba.

- 5. Dezember 18:00 – 20:00 Uhr
  - Ort: Gutbrod (Friedrichsplatz)
  - Thema: tba.

GREEN SOFTWARE
DEVELOPMENT & DESIGN

https://www.meetup.com/de-DE/green-software-development-stuttgart/