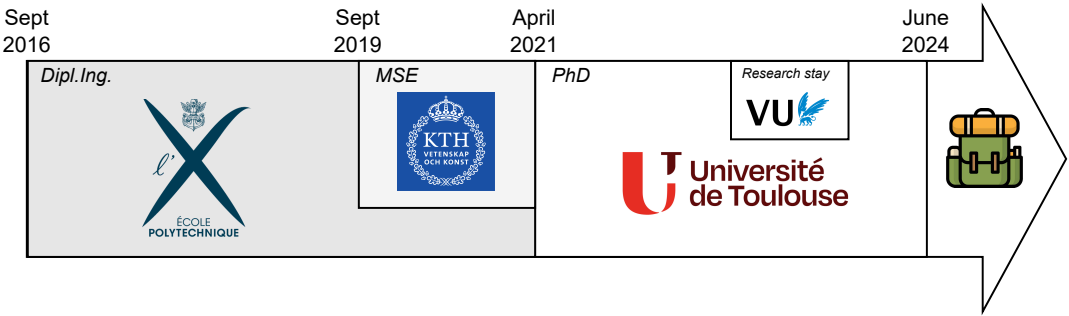
Digital Sufficiency in Data Centers

@Permacomputing Meetup #5, Vienna

Maël Madon

January 13, 2026

About me

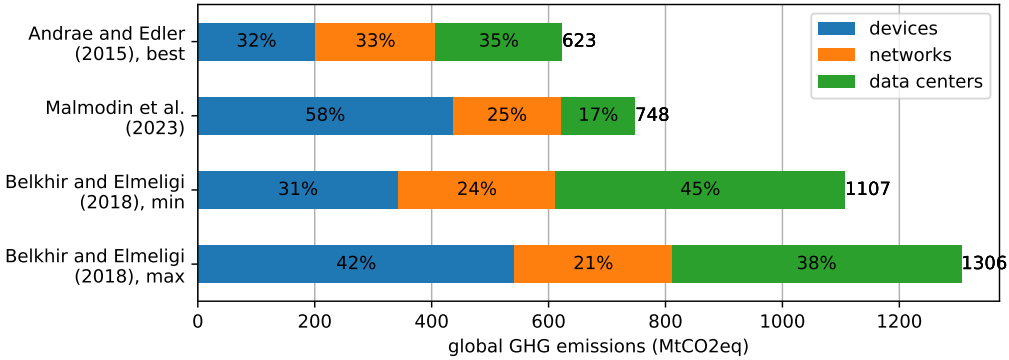


Interests: GreenIT, Distributed Systems, Digital Sufficiency

Context: greenhouse gas emissions from ICT

ICT industry = **2–4% global emissions**

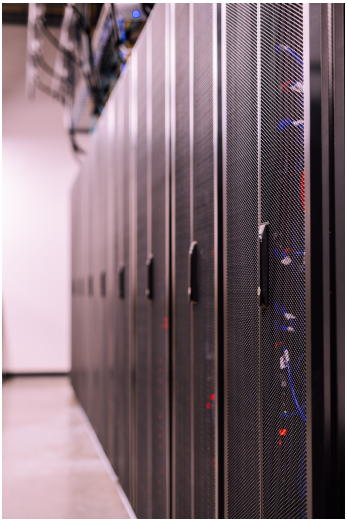
Global GHG emission estimates for ICT industry in 2020:



Footprint reduction in data center

Traditional techniques:

- **Energy efficiency** (virtualization, workload consolidation, DVFS...)
- **Use of renewable energies** (workload adaptation to power envelope, geographic load shifting, ...)
- **Data center environment** (cooling management, waste heat utilization, use of batteries)



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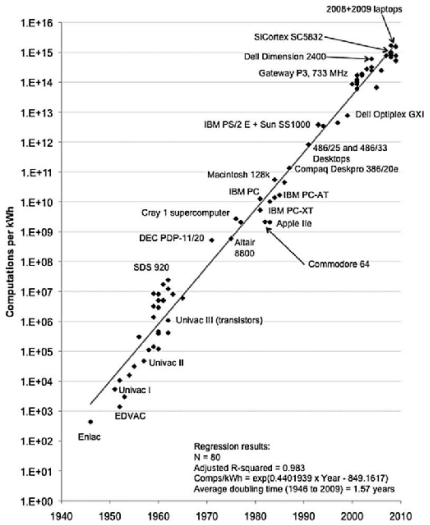
Energy efficiency

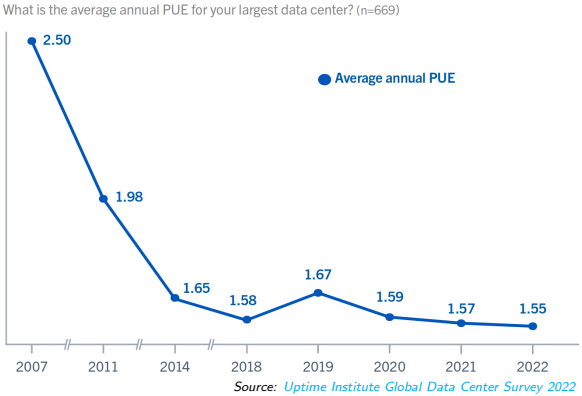
- **Koomey's law**: doubling the number of computations / kWh every 1.57 years



Source: Koomey et al. 2011

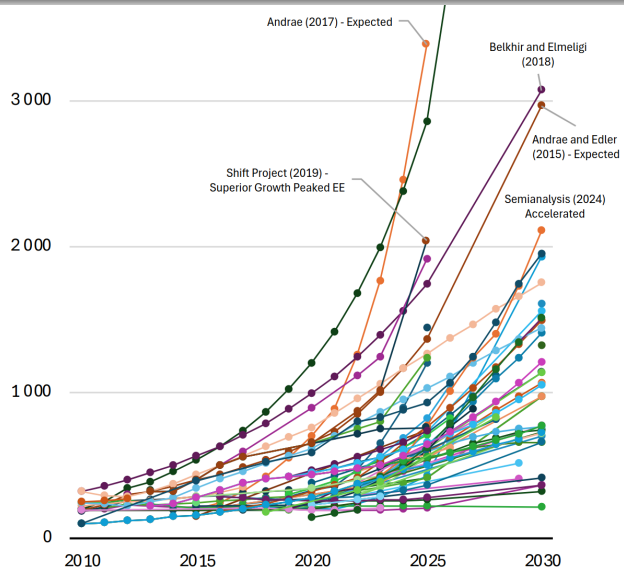
Energy efficiency

- **Koomey's law**: doubling the number of computations / kWh every 1.57 years
- **Power Usage Effectiveness**



Rebound effect

- **Data center energy estimates (TWh):**



Source: *Kamiya and Coroamă, 2025*

Efficiency is not enough: sufficiency

Sufficiency policies (IPCC, 2022)

A set of measures and daily practices that **avoid demand** for energy, materials, land and water **while delivering human well-being** for all within planetary boundaries.

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Digital sufficiency (Santarius et al., 2022)

Any strategy aimed at directly or indirectly **decreasing the absolute level of resource and energy demand from the production or application of IT**.

Four dimensions of digital sufficiency:

- **User sufficiency:** frugal use, IT for sufficiency-oriented lifestyles
- **Hardware sufficiency:** longevity, repairability
- **Software sufficiency:** long-term functionality, minimum data and utilization
- **Economic sufficiency:** IT for common good rather than economic growth

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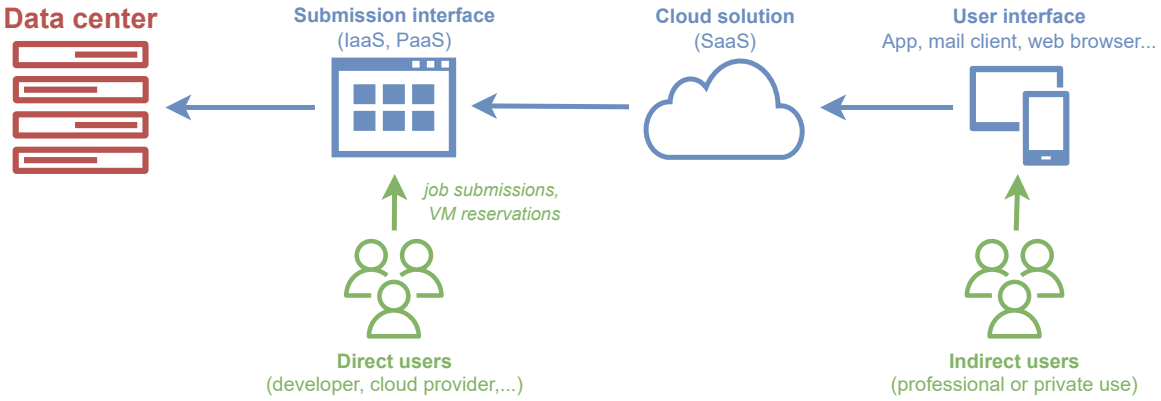
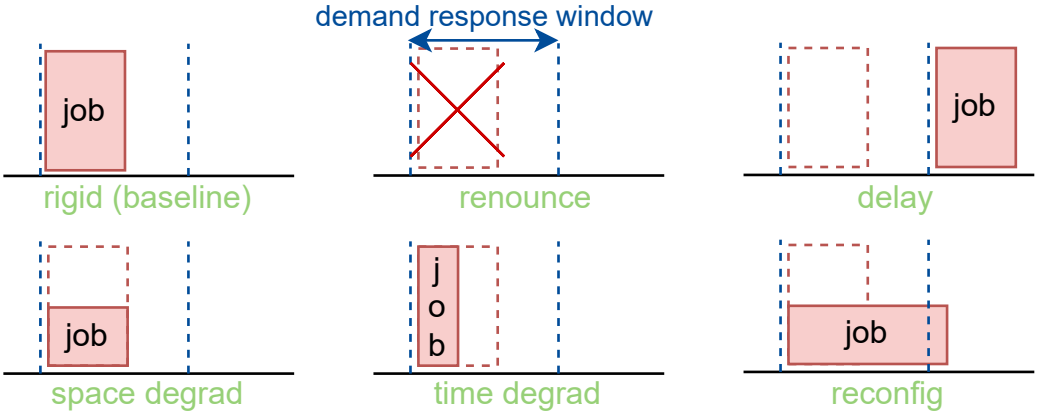
What would "sufficiency" mean for data centers?
→ voluntary limitation, empower and involve the user

Data center user?



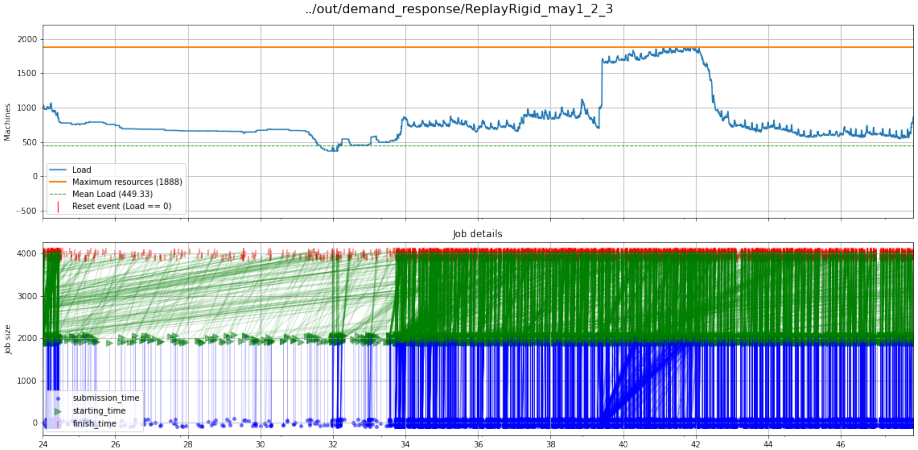
(cloud context)

“Sufficiency behaviors” for direct data center users



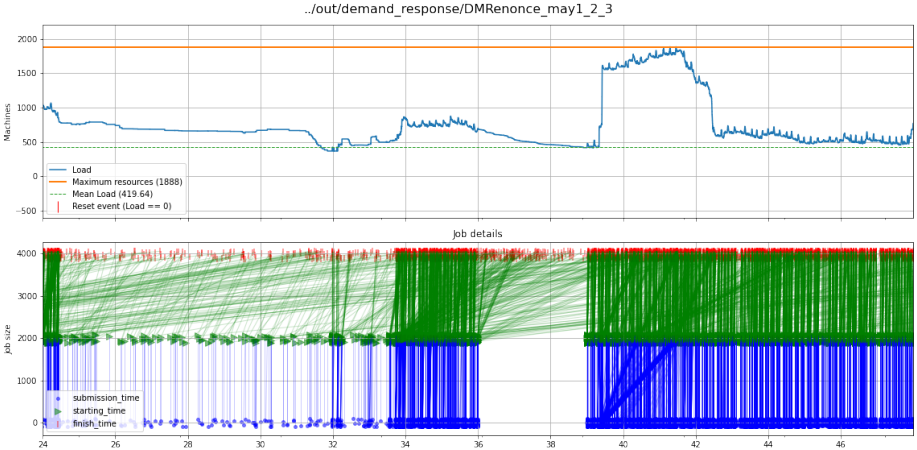
Output

- Behavior during demand response window: **rigid**



Output

- Behavior during demand response window: **renounce**

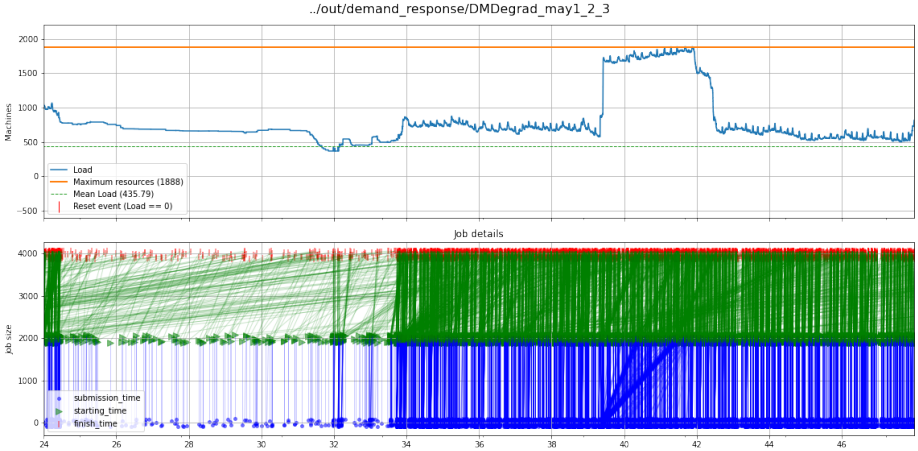


Output

- Behavior during demand response window: **delay**

Output

- Behavior during demand response window: **degrad**

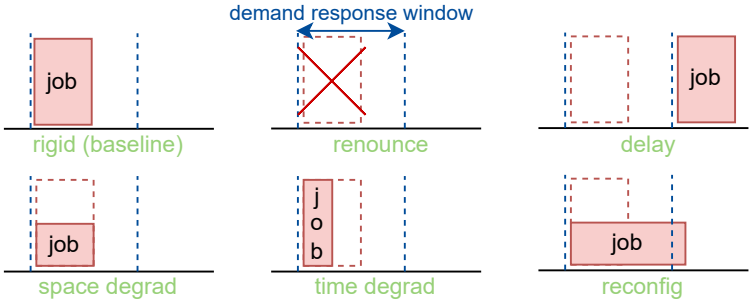


Output

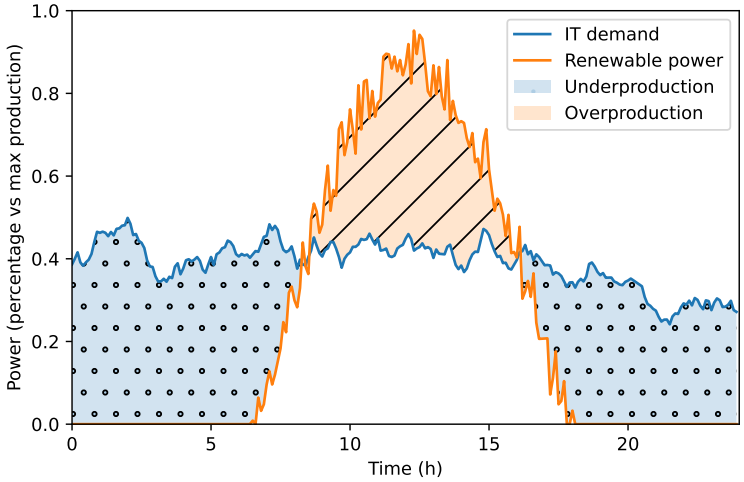
- Behavior during demand response window: **reconfig**

Results: pros and cons of each behavior

behavior	energy in	energy overall	sched. metrics	"acceptability"
renounce	1st	1st	1st	5th
delay	1st	5th	5th	2nd
space degrad	3rd	3rd	2nd	3rd
reconfig	3rd	4th	4th	1st
time degrad	5th	2nd	2nd	3rd



Sufficiency behaviors in a renewable context[1]



[1] J. Gatt, **M. Madon**, and G. Da Costa, 2024, Digital sufficiency behaviors to deal with intermittent energy sources in a data center, in: ICT4S 2024

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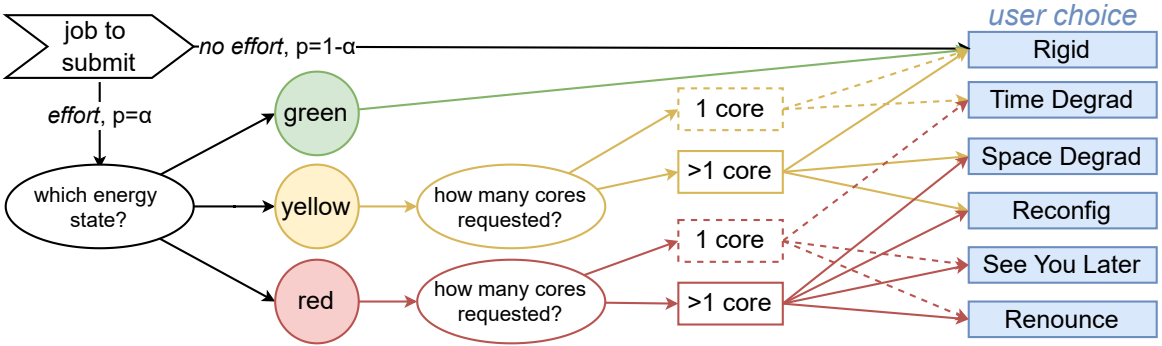

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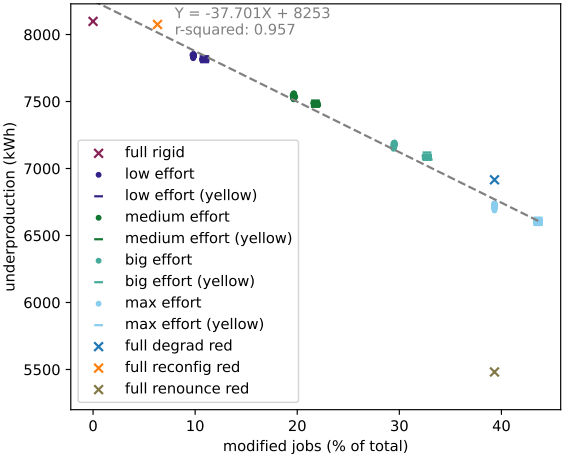
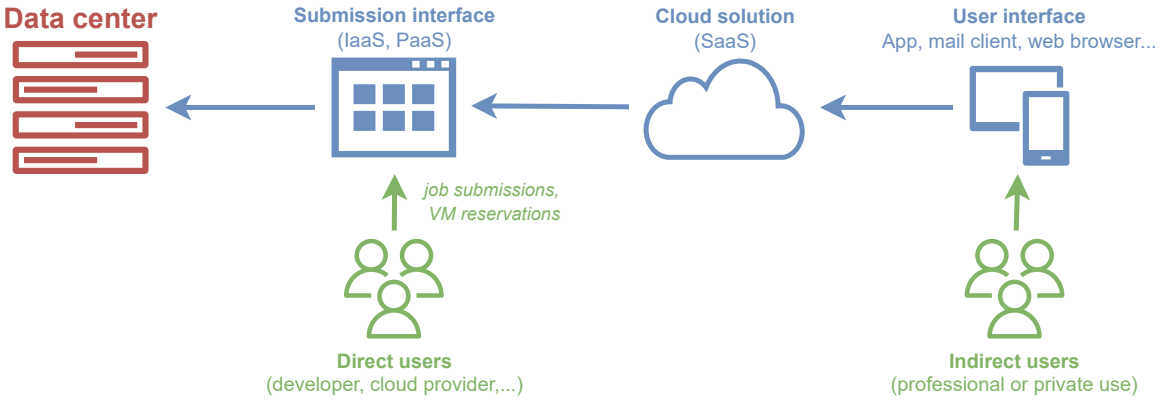
Results: energy gains VS user effort



Data center user?



(cloud context)

Sufficiency in cloud[2]

- **Context:** professional cloud usage w.r.t. environmental and social impacts
- **Question:** which cloud usage is *necessary* and which one is *superfluous* according to the practitioners?
- **Method:** focus groups and thematic analysis

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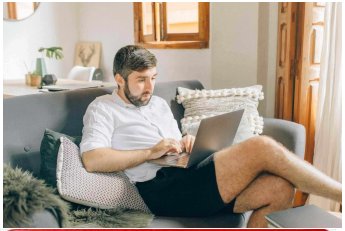


[2] **M. Madon** and P. Lago, 2023, "We Are Always on, Is That Really Necessary?" Exploring the Path to Digital Sufficiency in Flexible Work, in ICT4S 2023

List of digital usages for work

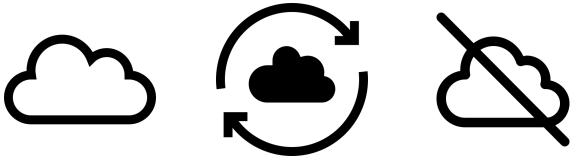
Task	#
email	9
messaging	6
planning	5
online meeting	5
phone	4
reviewing	4
project management	4
data analysis	4
preparing presentation	3
giving presentation	3
gathering information (internal)	3
gathering information (external)	3
writing time	2
writing documents	2
watching video	1
taking notes	1
online training	1
online presence	1
creating visuals	1
brainstorming	1
attending digital event	1

#: number of mentions of the task in the focus group discussions

"Everything is cloud-based in the work that we do"

Emily, HR Manager, 46-55 yo

- Categories of cloud-based tasks:



interactive

offline with regular synchronization

off-cloud

Necessary/superfluous: online meetings

"There's a bunch of meetings about meetings and pre calls for the meeting and then different meetings to evaluate the meetings. It's a lot of... yeah... meetings"

John, HR recruiter, 18-25 yo

Necessary	**Superfluous**
Save travel time	Too many meetings
To keep human contact	Too long meetings
Easier to arrange	Recurring meetings
For team work	Duplication of channels
Camera for facial expressions	...
...	

Tactics towards sufficiency

- **48 tactics towards sufficiency** extracted from the discussions

Examples


Turning the video off in an online meeting


Setting a lower value for the default meeting duration


Cancelling the next session of a recurring meeting when it has no purpose


Decreasing the frequency of a recurring meeting

Tactics towards sufficiency

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	Examples	**Suff. behavior?**
	Turning the video off in an online meeting	→ Space Degrad
	Setting a lower value for the default meeting duration	→ Time Degrad
	Cancelling the next session of a recurring meeting when it has no purpose	→ Renounce
	Decreasing the frequency of a recurring meeting	→ Delay? Degrad?

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Examples	**Suff. behavior?**
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- Categorization of the tactics into
  - 38 human-oriented / 5 system-oriented / 6 context-oriented

  → echoes digital sufficiency dimensions

Conclusion

- Going beyond *efficiency*, investigating *sufficiency* for data centers
  - simulation of "sufficiency behaviors" for **direct data center users**
  - interview of **indirect data center users** (cloud users)
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  - main driver of data center growth: **AI**
  - users, governments, small companies are powerless...

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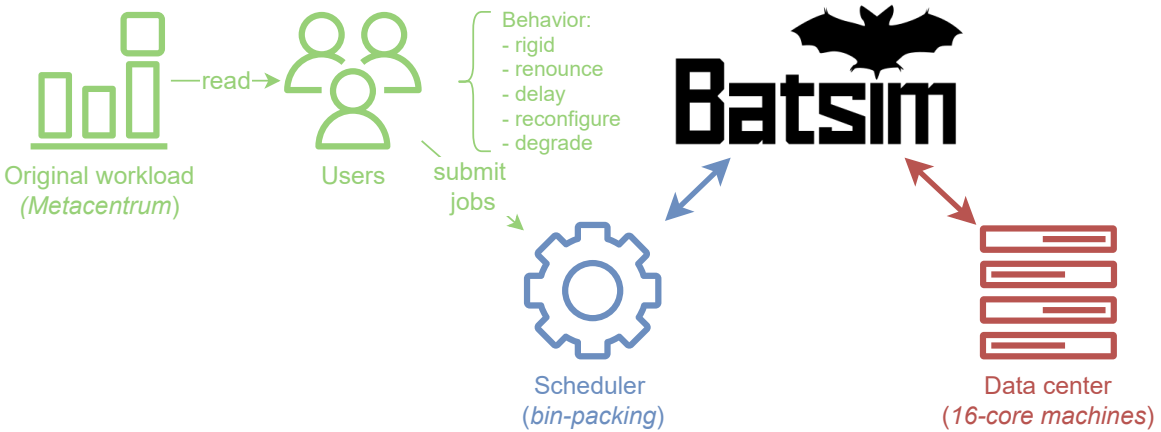
- Do not hesitate to contact me :-)
  - https://maelmadon.github.io/
  - mael.madon@m4x.org

The simulated system



Fluid and residual mass