

# ***OpenInfra***

*Co-simulation Framework for the Infrastructure Nexus*

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*HotInfra' 24*



UC Berkeley

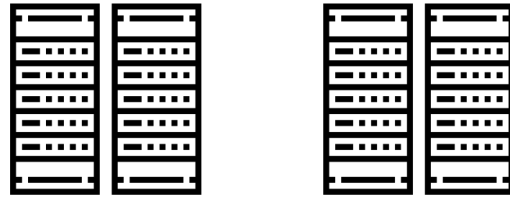


# What is the Infrastructure

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## Infrastructure:

- Cloud Infrastructure: Datacenter
- Industrial Infrastructure: Power Plant, Water System



Datacenter



Power Plant

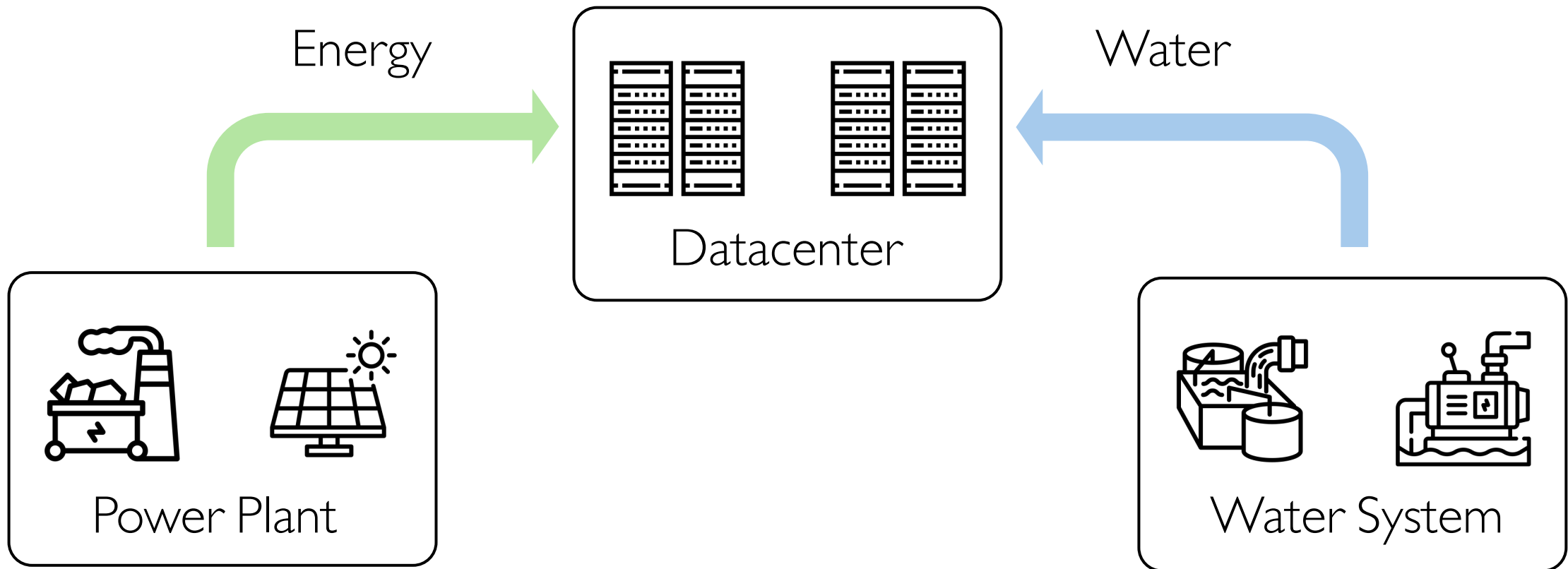


Water System

# What is the Infrastructure Nexus

## Datacenter/X Nexus: Datacenter/Energy, Datacenter/Water:

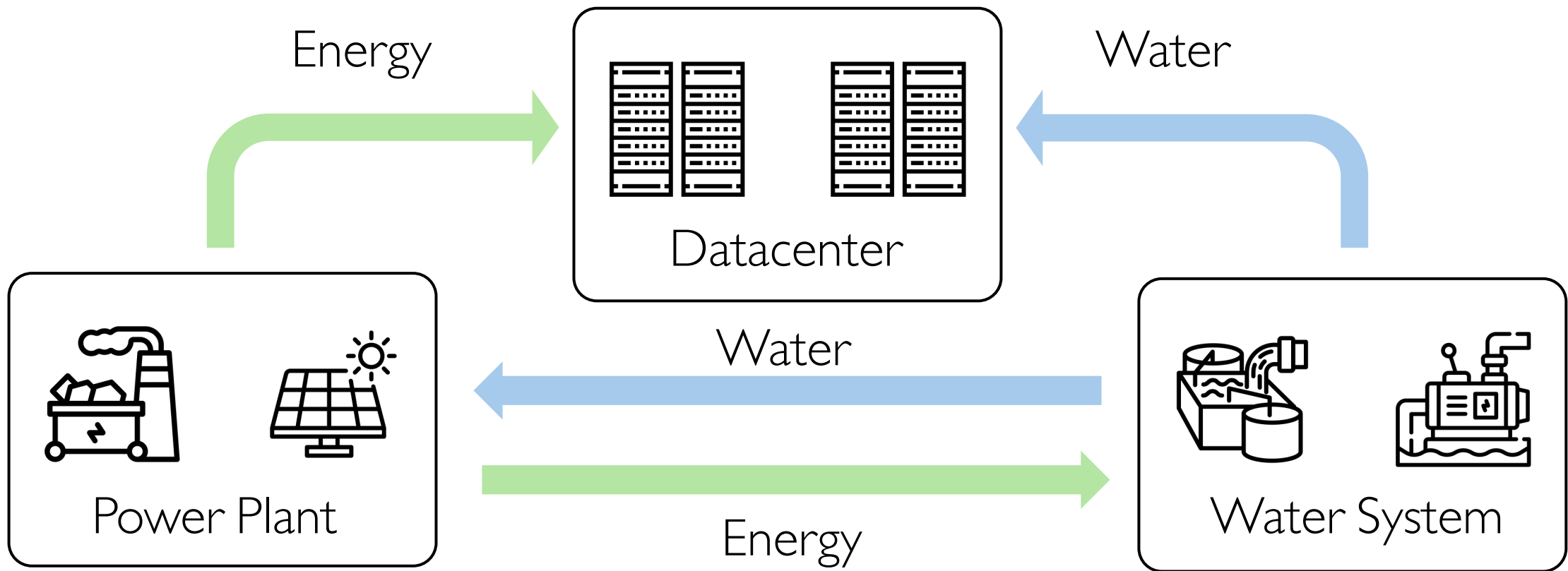
- Datacenter requires energy to power its facilities
- Datacenter requires water to cool IT equipment



# What is the Infrastructure Nexus

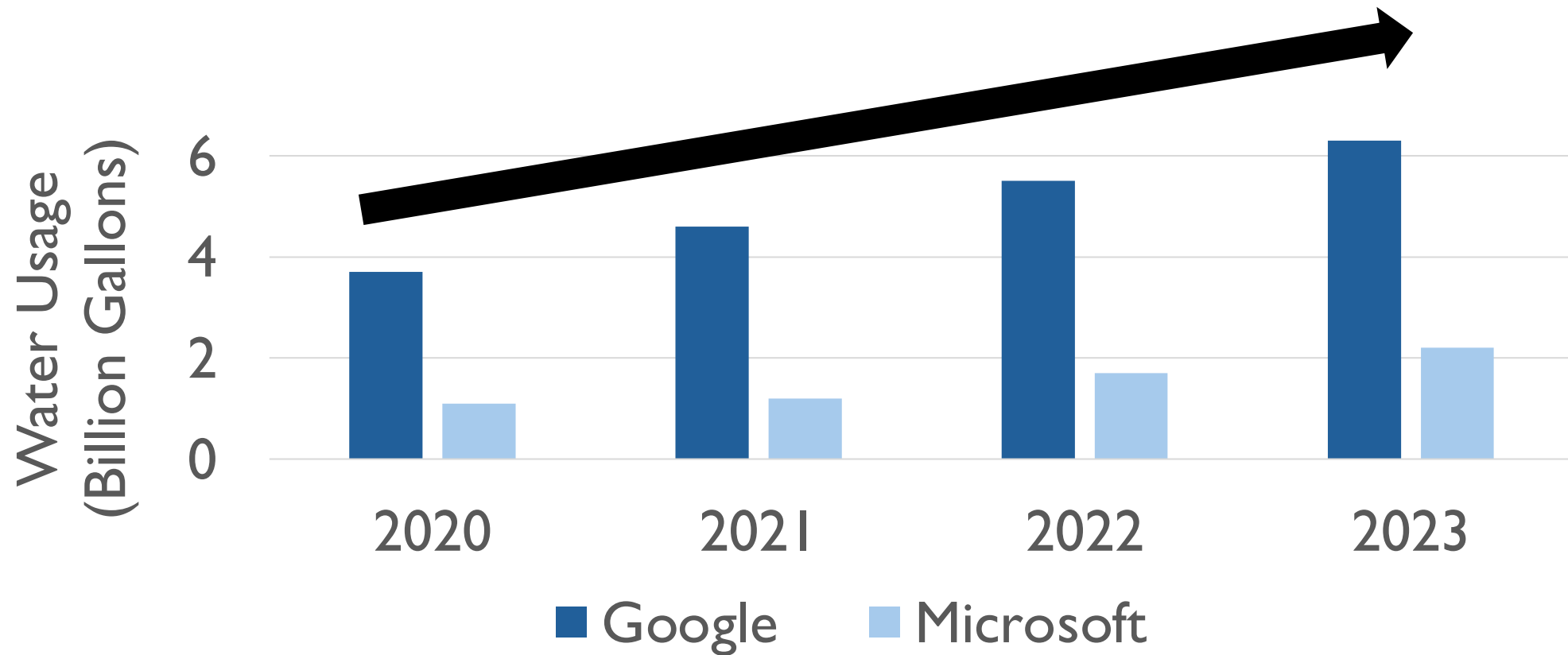
## Power/Water Nexus:

- Power Plant requires water to cool its equipment
- Water System requires energy to pump and filter water



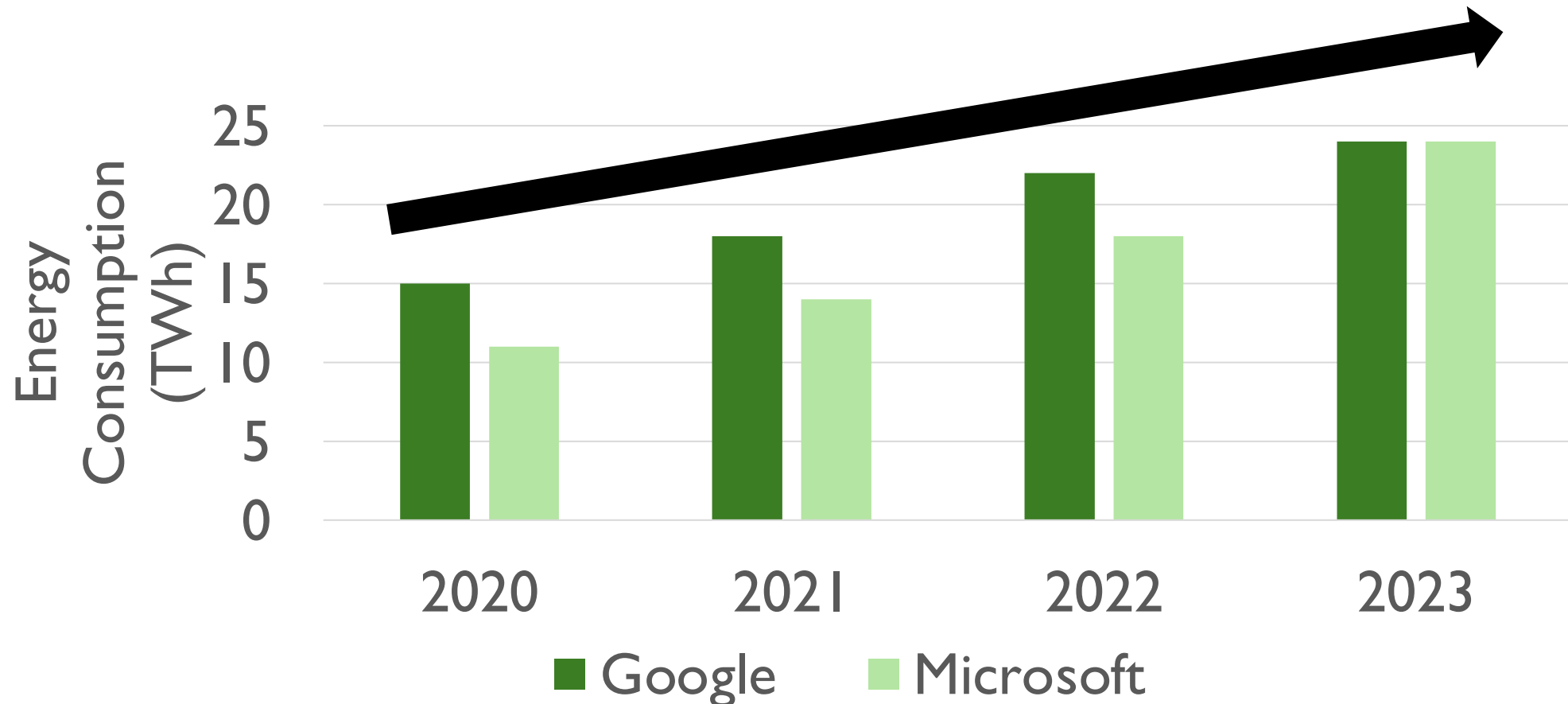
# Why is the Infrastructure Nexus important?

- Datacenter water usage increases quickly



# Why is the Infrastructure Nexus important?

- Datacenter power usage keeps increasing



Source:

<https://www.goldmansachs.com/insights/articles/AI-poised-to-drive-160-increase-in-power-demand>

<https://www.visualcapitalist.com/microsofts-electricity-use-has-doubled-between-2020-2023/>

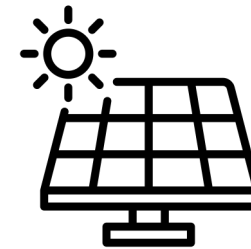
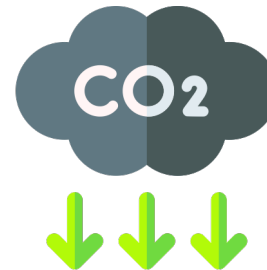
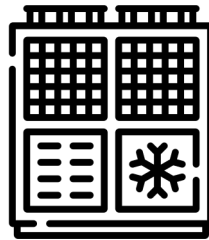
<https://www.statista.com/statistics/788540/energy-consumption-of-google/>

# Opportunities at the Infrastructure Nexus

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## Co-optimization to balance power and water usage trade-offs

- Cooling datacenters at night is more water-efficient because of low temperature
- Powering datacenters at night is less carbon-efficient because of less renewable energy

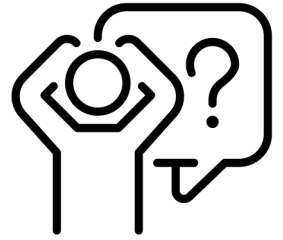


# Why we need the co-simulation framework

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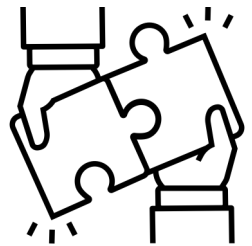
## Problem:

- Direct evaluation on multiple physical infrastructures is hard!
- Requires expertise across multiple domains.



## What is co-simulation:

- A complex system composed of individual simulators.



## Why co-simulation:

- Easy integration of high-fidelity simulators from multiple domains.





# OpenInfra goals

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OpenInfra

...

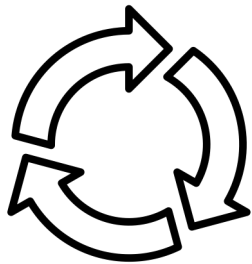
Embed more infra sim.

Water Sys Sim.

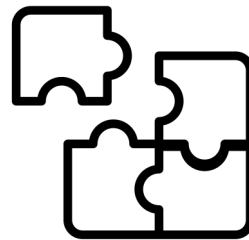
Power Plant Sim.

Datacenter Sim.

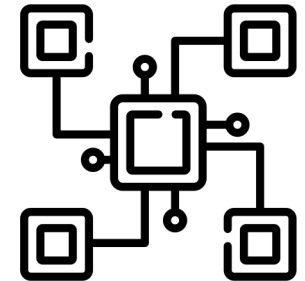
Wireless Sys Sim.



Reuse Simulators



Seamless Integration



Simulator Interactions

# Co-simulation for Infrastructure Nexus is hard

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Heterogenous types of  
simulators required



Each types has  
many simulators



OMNet++



Carbon Explorer



Datacenter simulator

Power Plant simulator

5G simulator

# System level challenges

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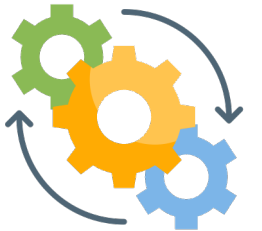
- **Language:**

Requiring an intuitive language to define nexus experiments



- **Execution:**

Performance limited by slowest simulators and resource constraints.



- **Scalability:**

High communication overhead in distributed simulators.



# System level challenges - Cont'd

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- Algorithm

Easy integration with existing libraries for various simulation goals.



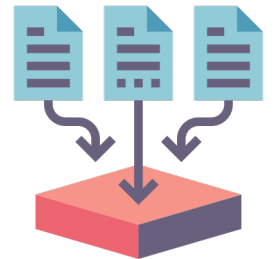
- Synchronization

Synchronize and translate events across simulators.

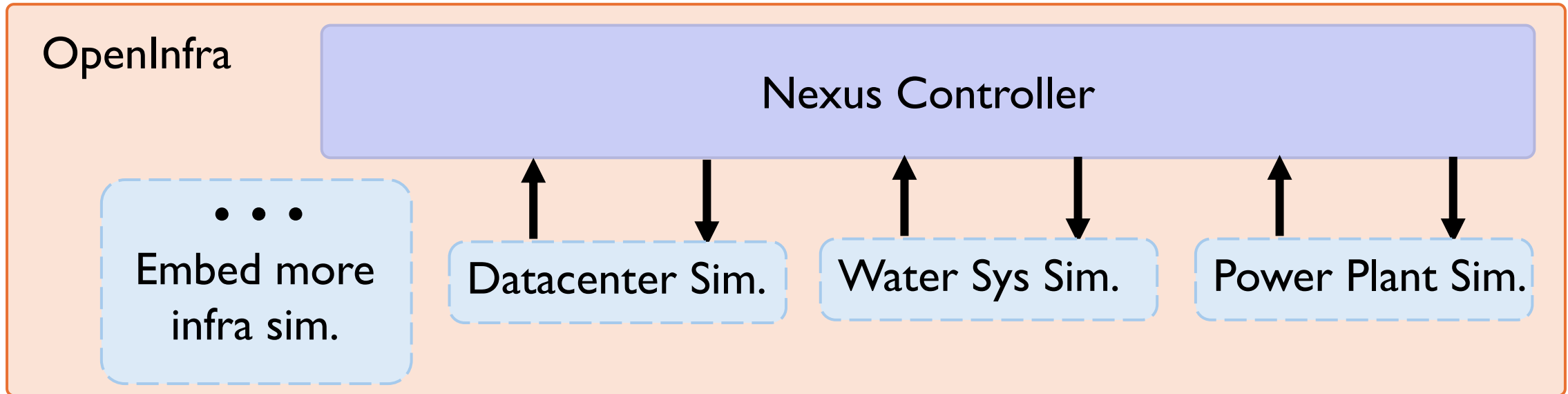


- Data management

Handle diverse data formats across simulators.

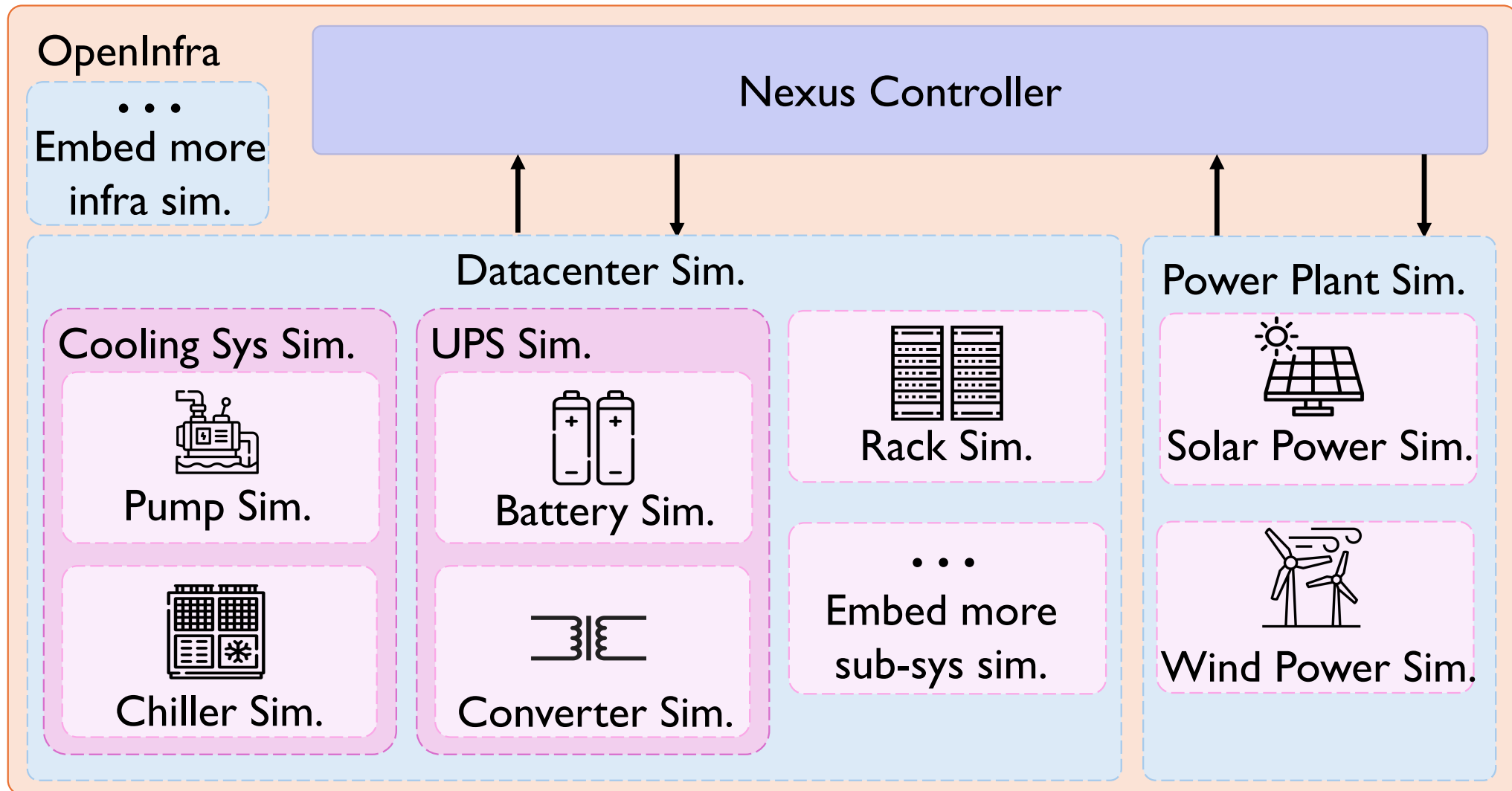


# OpenInfra Architecture



- `State()`: expose internal state variables from a simulator to OpenInfra
- `Actuate()`: trigger specific actions within a simulator
- **Capabilities**: Co-optimization and specific event creation (e.g., infrastructure failure)

# OpenInfra Architecture - Cont'd



# Infrastructure-as-Code management

- Multi-level IaC to fit multiple hierarchies of simulation

```
1 "datacenter": {
2   "granularity": "rack_level",
3   "rack_number": 2,
4   "server_number_per_rack": 52,
5   "UPS_redundancy": "n+1",
6   "UPS_battery_attribute": "...",
7   "connected_rack_number_per_PDU": "1",
8   "PDU_redundancy": "2n"
9 }
```

Initial Stage IaC file



```
1 // Other components ...
2 "Racks": [
3   {
4     "rack_id": 1,
5     "priority": 1,
6     "number_of_servers": 52
7   },
8   {
9     "rack_id": 2,
10    "priority": 2,
11    "number_of_servers": 10 // original 52
12  }
13 ]
```

Final Stage IaC file

# What we have supported

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- **Integrate 17 simulators**
  - 8 types of power plant simulators
  - 3 types of Uninterruptible Power Supply (UPS) simulators
  - Datacenter rack (load/power usage) simulators
  - Pump/Chiller simulators
  - Datacenter/Power plant water usage simulators
- **Working prototype available on GitHub:** <https://github.com/JhengLu/OpenInfra>
  - Written in Python with 4,000 lines of code
  - Active expansions and improvements are in progress
  - All contributions are welcome!



# Simulation results

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## Setting:

- Data center with 7,392 servers and 5 UPS units, running for 100 hours
- Two renewable power plants: wind and solar
- Power plant follows the EIA trace<sup>[1]</sup>
- Server load follows the Google trace<sup>[2]</sup>

## Speed:

- Runs in 5 seconds on MacBook Pro M2 Max

Source:

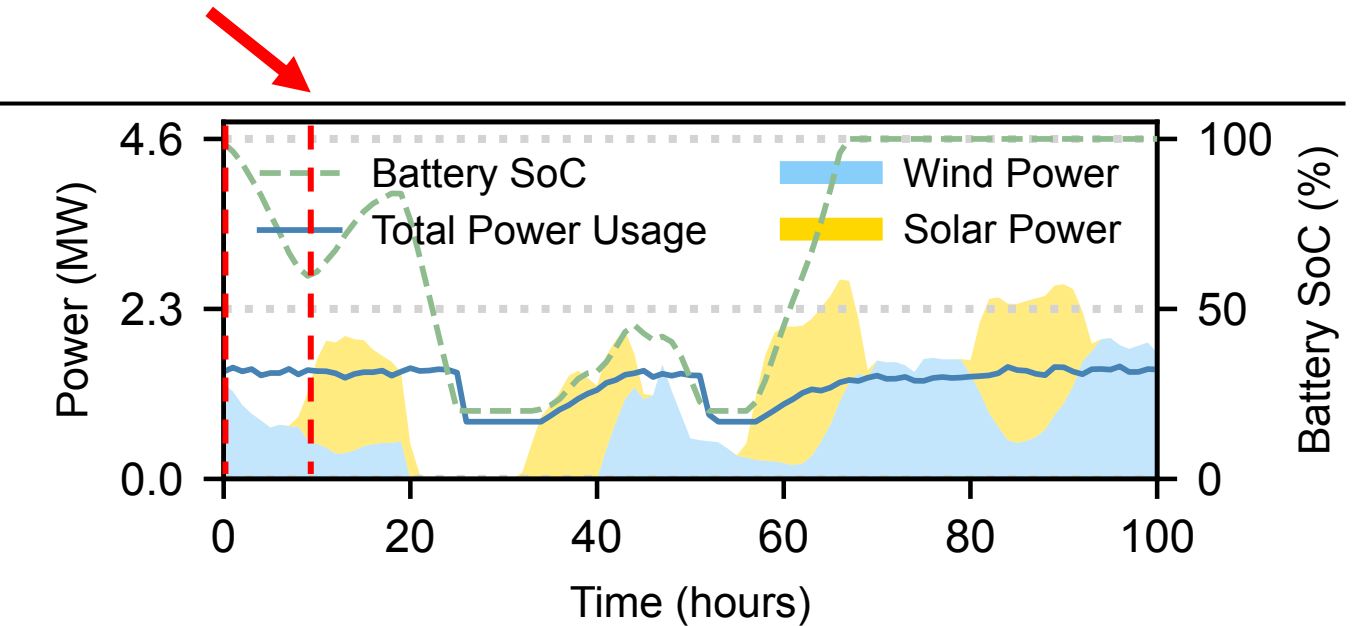
[1]: <https://www.eia.gov/>

[2] M. Tirmazi, A. Barker, N. Deng, M. E. Haque, Z. G. Qin, S. Hand, M. Harchol-Balter, and J. Wilkes. Borg: the next generation. In Proceedings of the fifteenth European conference on computer systems, pages 1–14, 2020

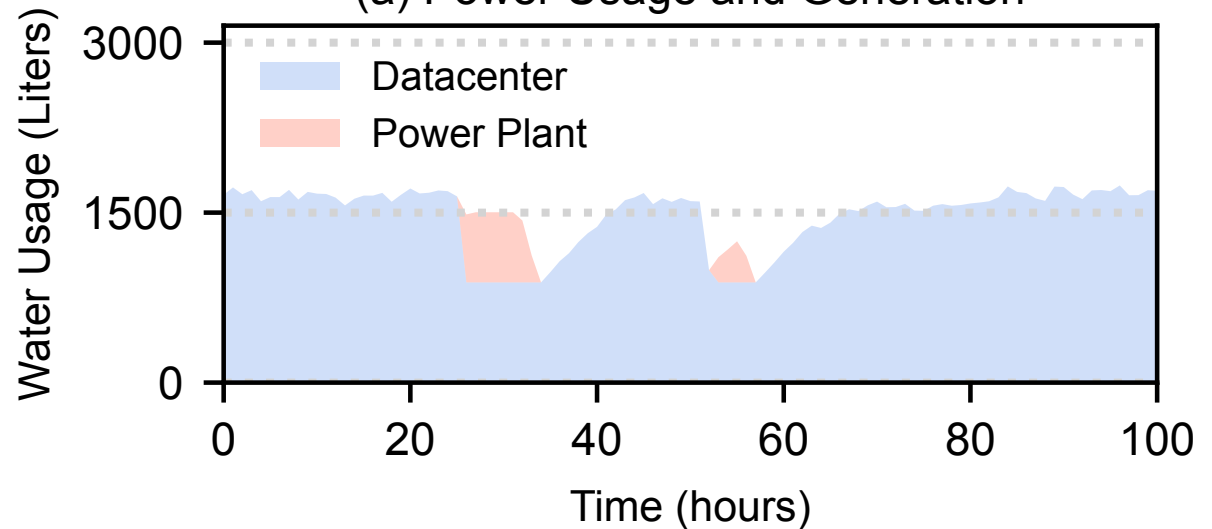
# Simulation results

0-10h

- consumption > renewable supply, battery SoC drops



(a) Power Usage and Generation

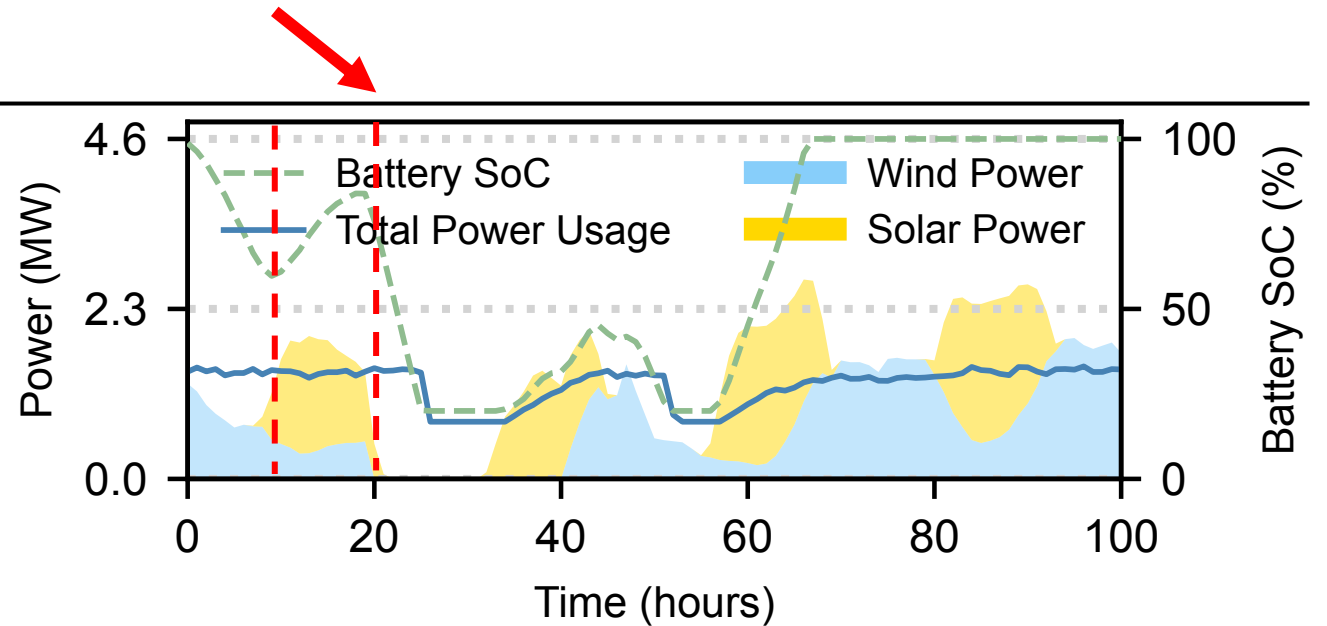


(b) Water Usage (Datacenter and Power Plant)

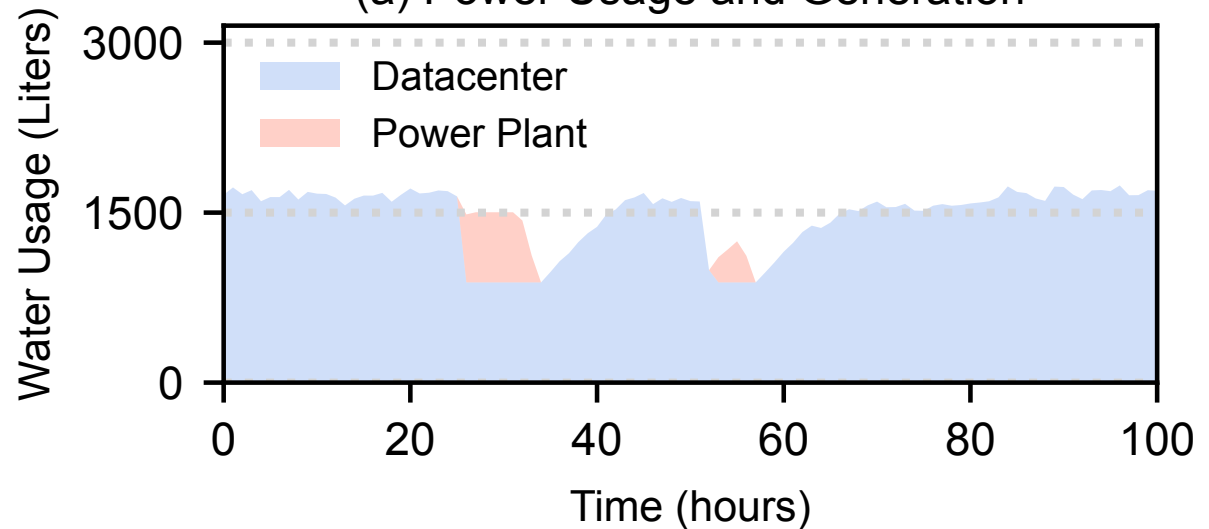
# Simulation results

10-20h

- Consumption < renewable supply, battery recharge



(a) Power Usage and Generation

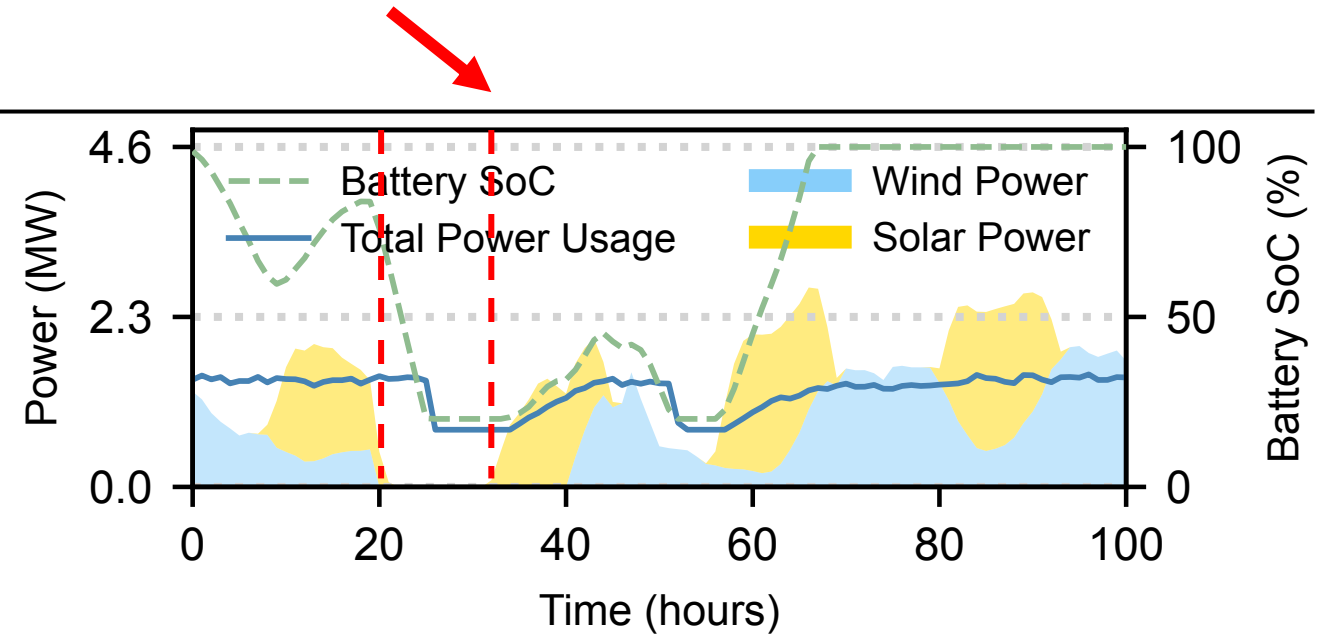


(b) Water Usage (Datacenter and Power Plant)

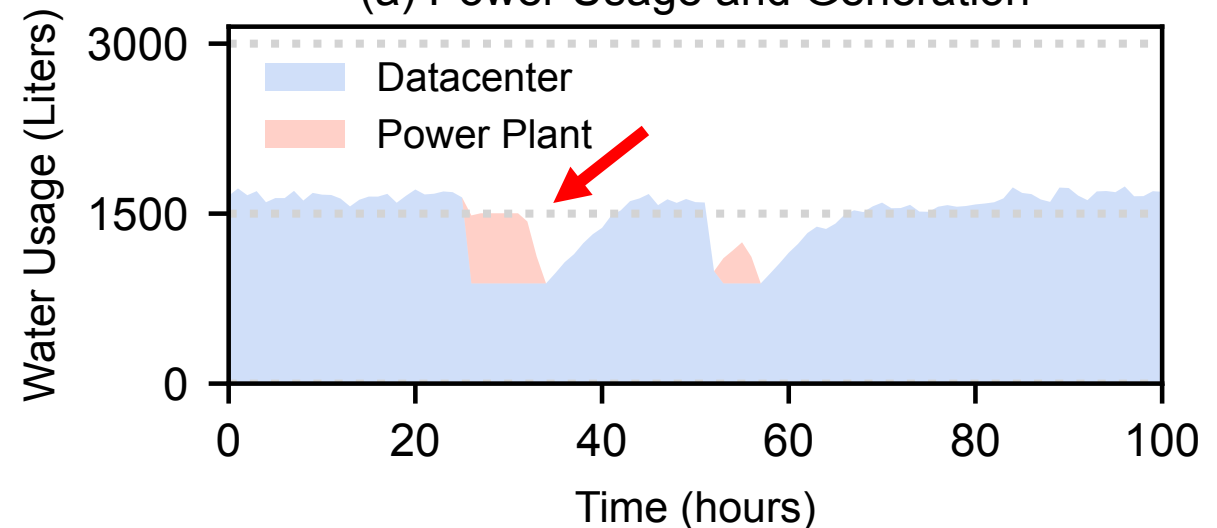
# Simulation results

20-32h

- The wind power plant failure is intentionally created, and the solar power naturally disappeared because it is nighttime



(a) Power Usage and Generation

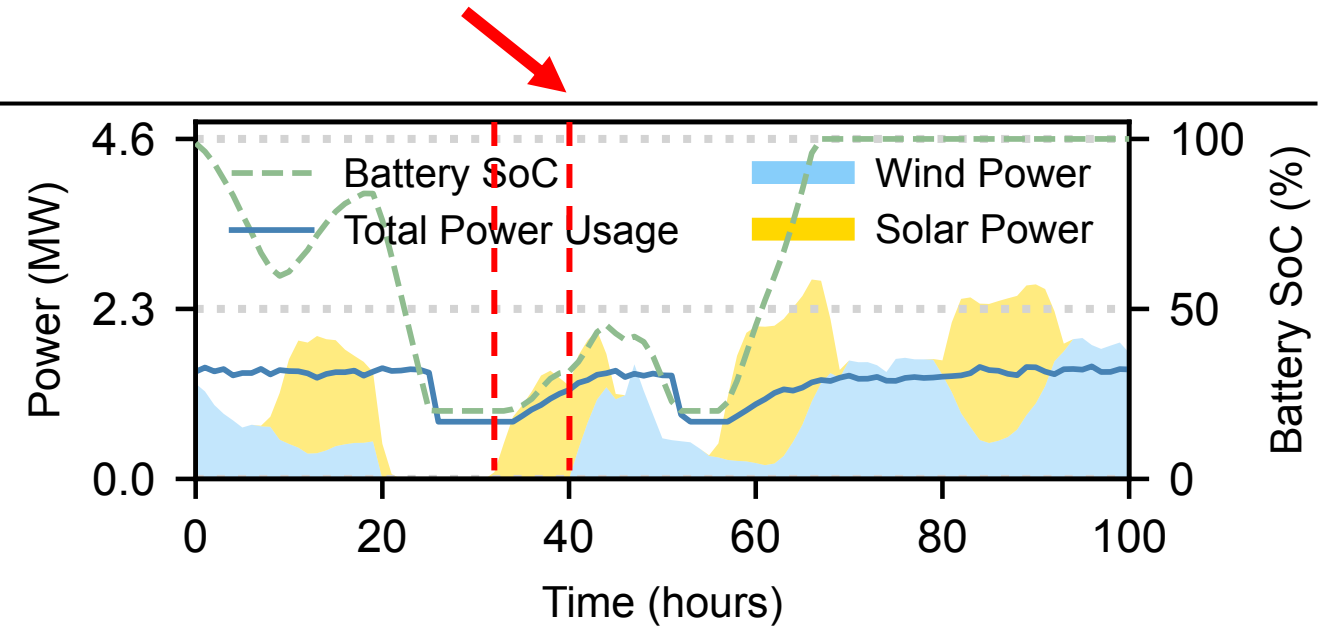


(b) Water Usage (Datacenter and Power Plant)

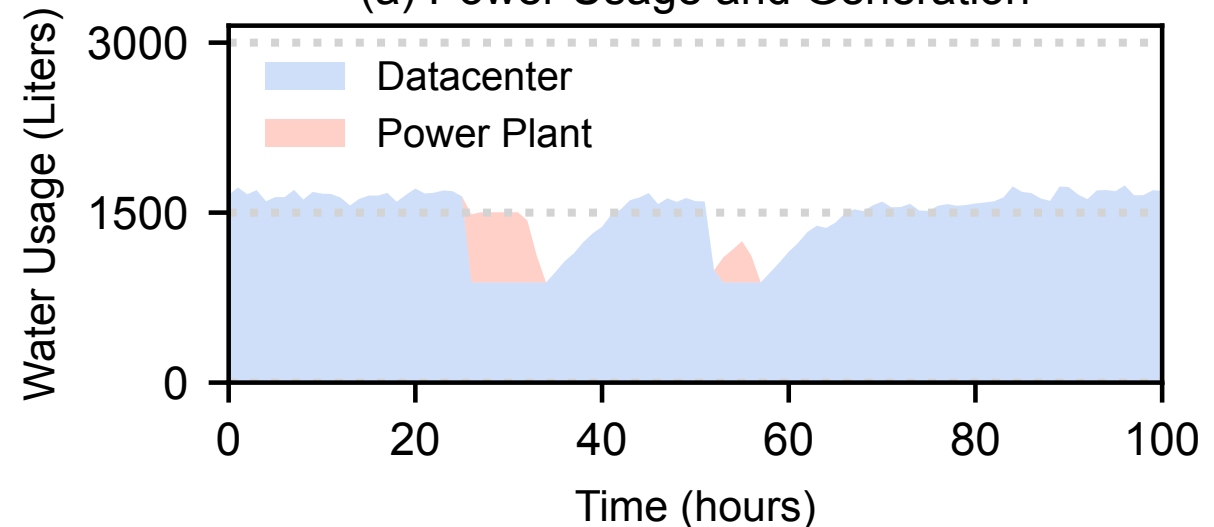
# Simulation results

## 32-40h

- consumption < renewable supply, solar power recovers, battery gets charged



(a) Power Usage and Generation

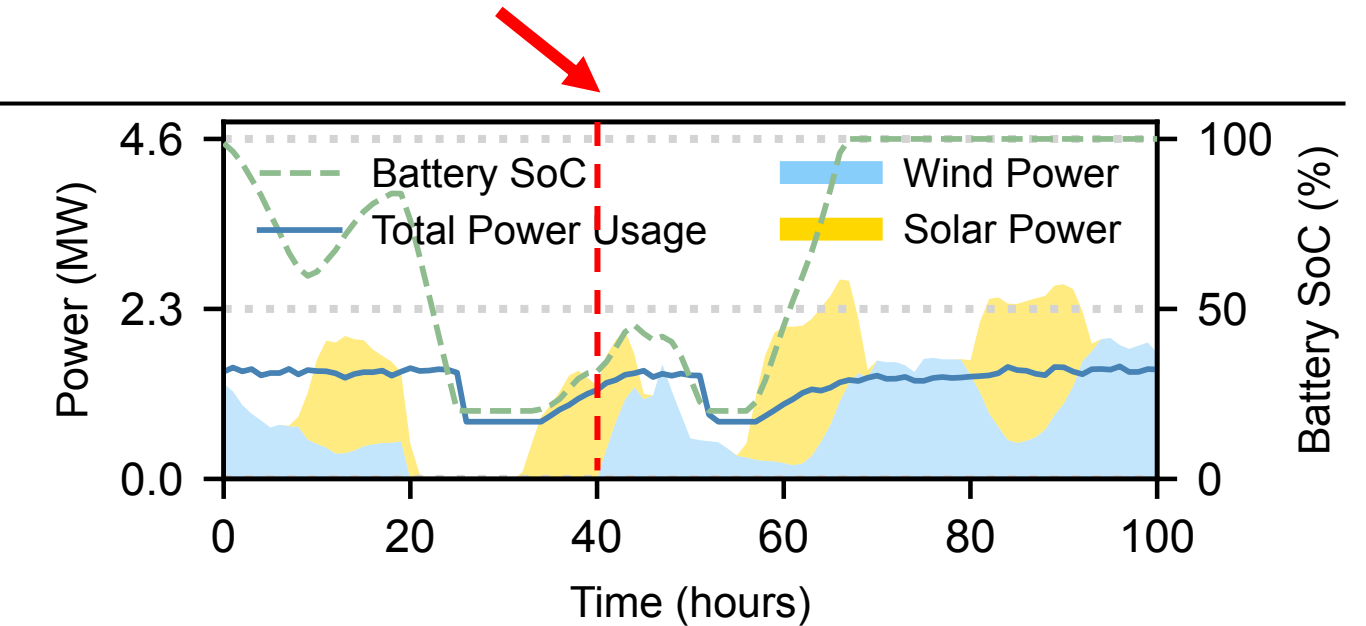


(b) Water Usage (Datacenter and Power Plant)

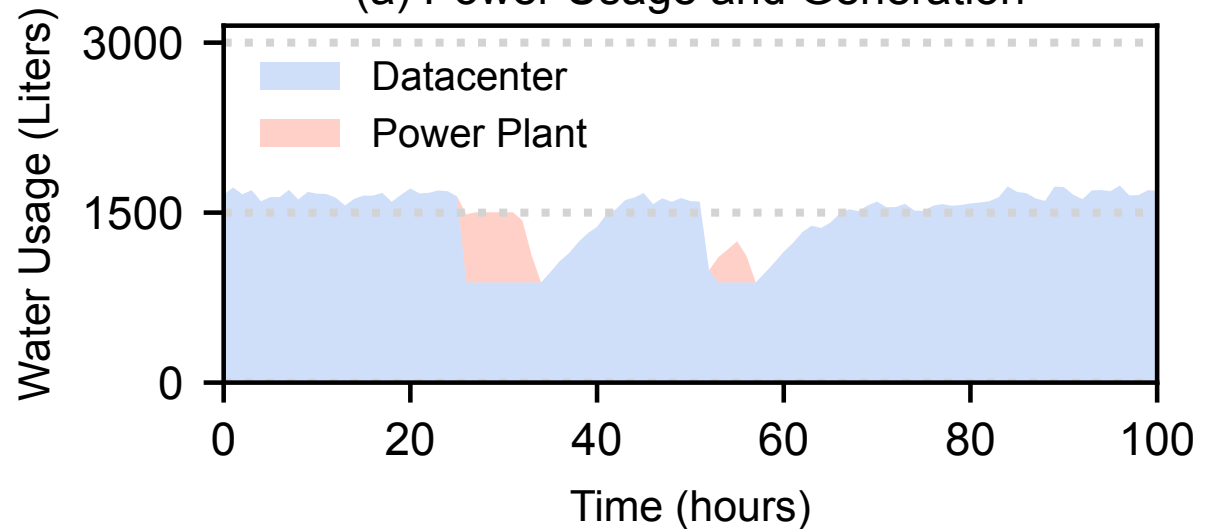
# Simulation results

40h onwards:

- Wind power failure ends



(a) Power Usage and Generation

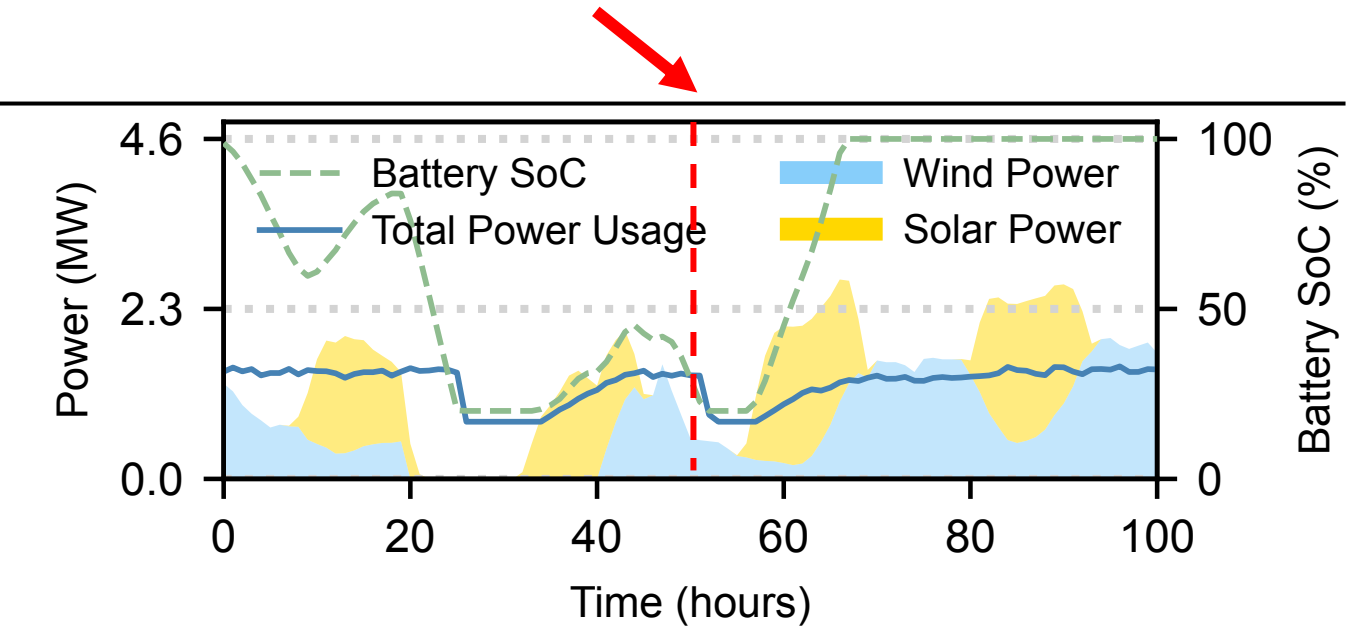


(b) Water Usage (Datacenter and Power Plant)

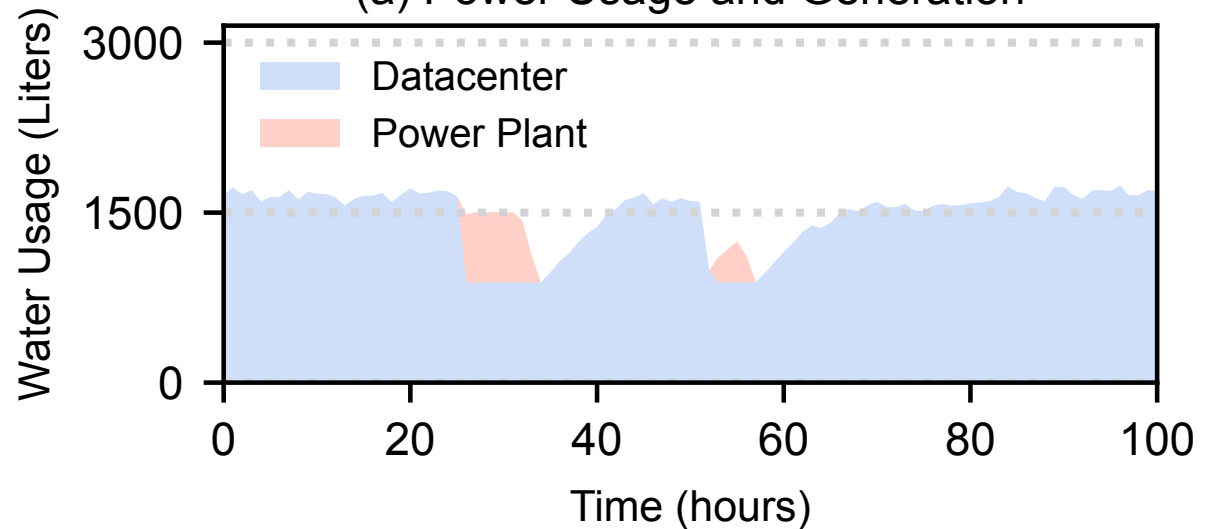
# Simulation results

At 50h:

- Power supply drops



(a) Power Usage and Generation

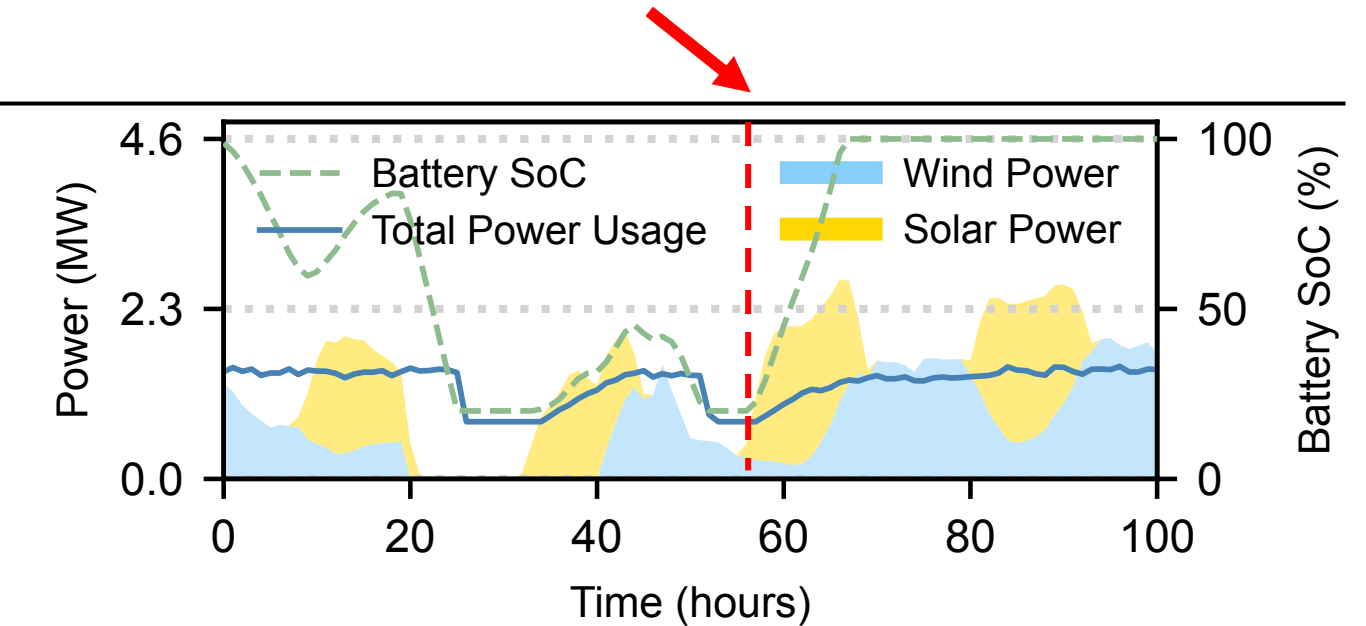


(b) Water Usage (Datacenter and Power Plant)

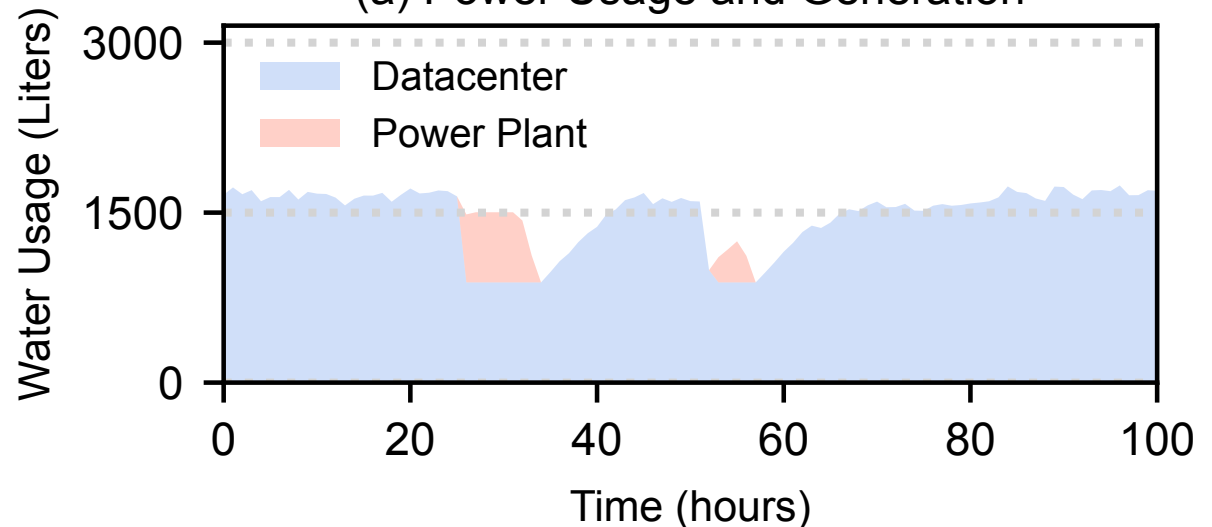
# Simulation results

After 55h:

- Power supply stabilizes



(a) Power Usage and Generation



(b) Water Usage (Datacenter and Power Plant)



# Conclusion

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- What is the Infrastructure/Infrastructure Nexus
- Goals, Challenges, and Architecture of OpenInfra
- Future work:
  - Developing a programming model for the co-simulation framework
  - Exploring containerized simulator management using Kubernetes
  - Enabling zero-modification integration for new simulators
  - Expanding simulation use cases
- I am actively searching for PhD positions for Fall 2025!

*Thank you! Feel free to reach out for a chat!*  
*Jiaheng Lu    [jiahenglu.com](http://jiahenglu.com)*