Services Orchestration at the Edge and in the Cloud on Energy-Aware Precision Beekeeping Systems

Hugo Hadjur (aivancity Paris-Cachan, ENS de Lyon)
Doreid Ammar (aivancity Paris-Cachan)
Laurent Lefèvre (Inria, Univ Lyon, ENS de Lyon, UCBL, CNRS, LIP)
hugo.hadjur@ens-lyon.fr, ammar@aivancity.ai laurent.lefevre@inria.fr

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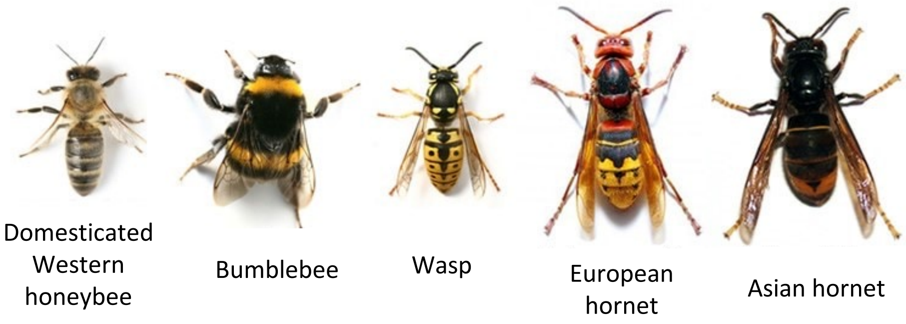
The context of this research – Fighting against Colony Collapse Disorder

- Pesticides
- Varroa destructor mite
- Genetic constraints
- Habitat destruction
- Asian hornet
- Viruses

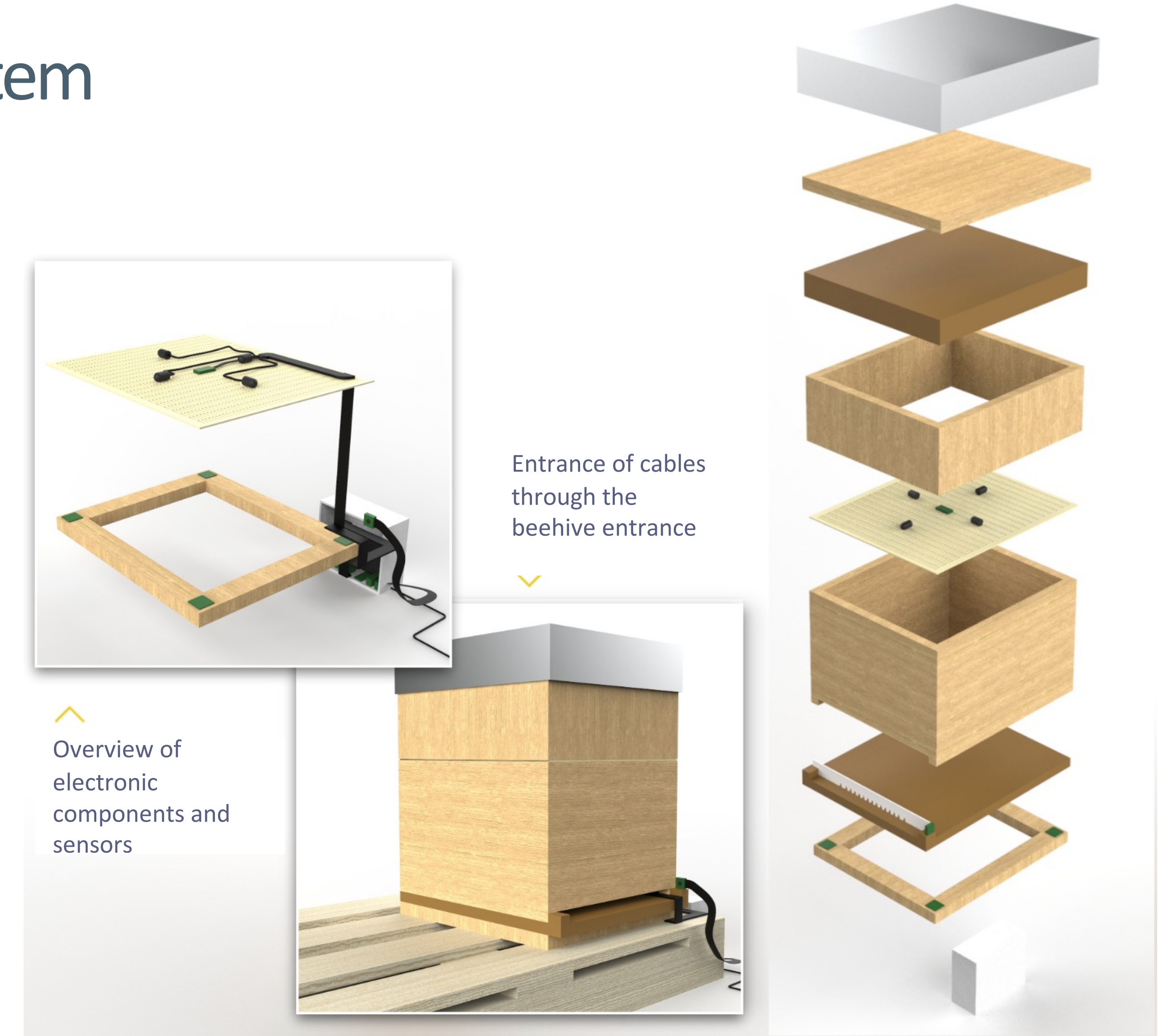


Goals of this research

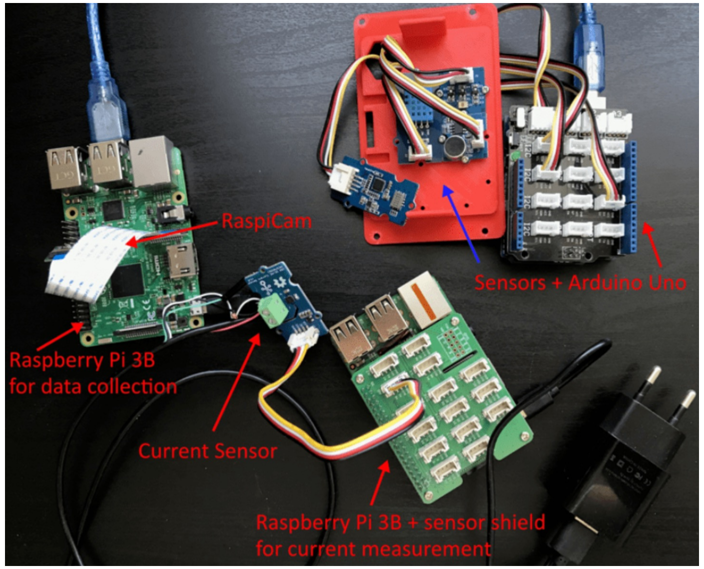
- Design a cheap, open source smart beehive
- Provide services to bees and beekeepers
- Collecting and sharing on site data
- Explore autonomous behavior in terms of energy consumption and energy efficient design
- Being frugal at every level (data, energy, …).

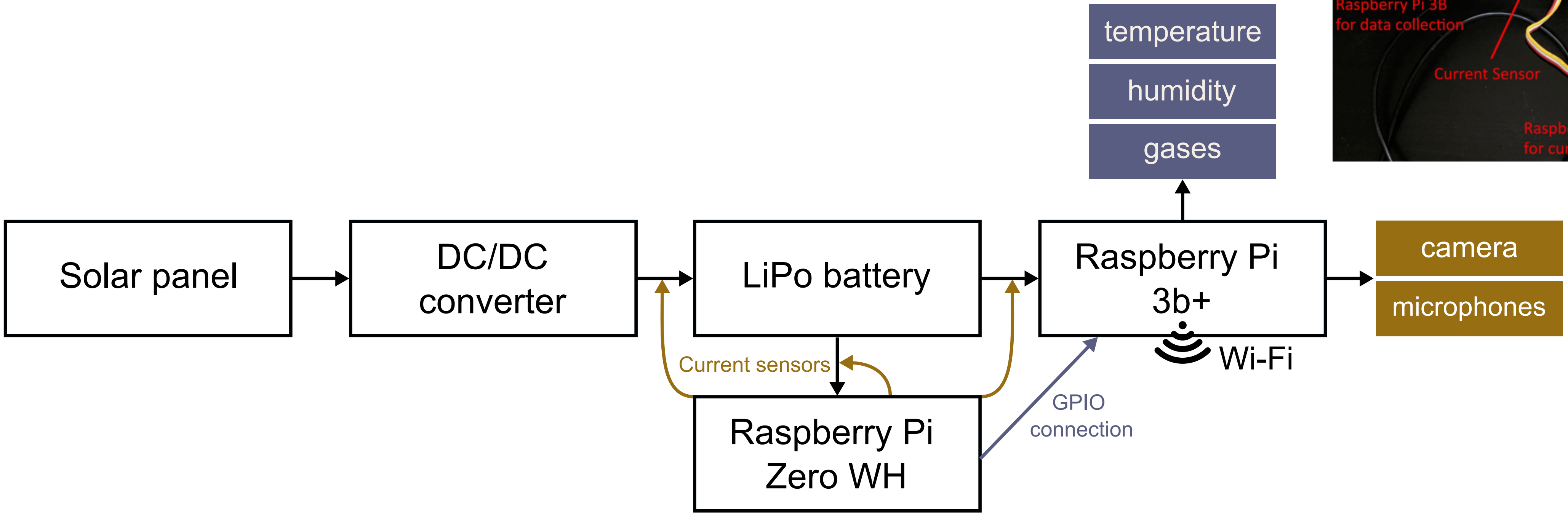
Designing a smart beehive system

- Designed to keep instrusivity low
- Our system base: a Raspberry Pi
- Sensors: temperature, humidity, gas, sound and image
- Energy source: solar panels
- Network: data sent to Cloud servers through Wi-Fi or 4G
- Embedded intelligence on the Edge and on the Cloud: AI models
- Open system, low cost



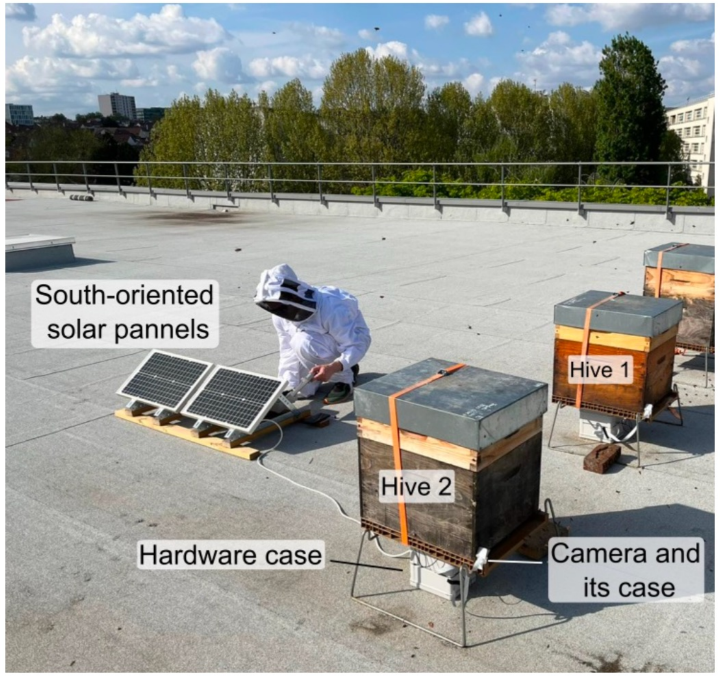
Designing a smart beehive system

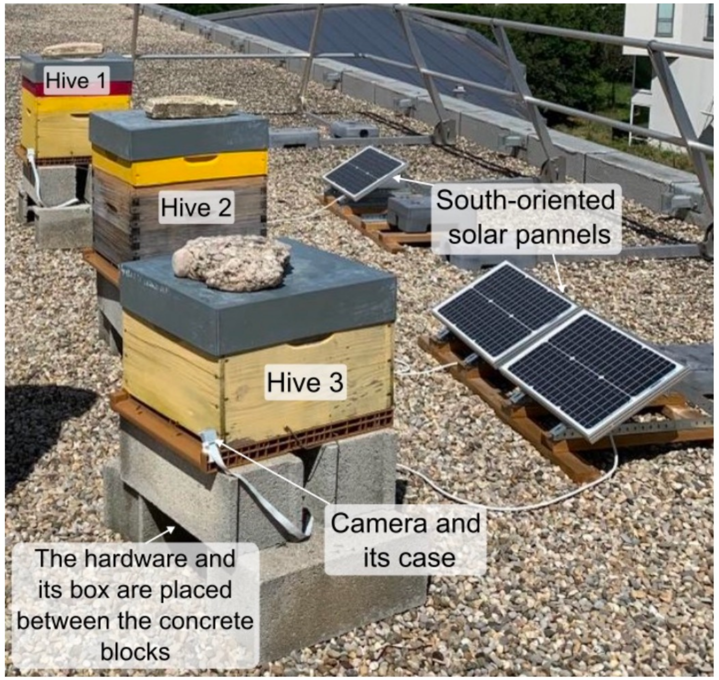




On site deployment

- Focus on urban honeybee beehives
- Deployment of 5 smart beehives
  - 3 in Lyon (France)
  - 2 in Paris (France)
- Open to students projects
- Our system is able of collecting at all time the energy production and consumption data and of collecting apiary data at regular intervals.





Paris (Cachan) and Lyon deployment sites

Our roadmap

Initially : deploy as much as possible services on the smart beehives (edge)
-> continuous measurements and data collect
-> reactivity
-> autonomous system..etc…

First illustrative focus : AI services -> queen detection

In reality :
-> energy production is limited, energy budget is limited
-> battery issues

Data collection cannot work permanently -> On/Off

Must balance between Edge and Cloud servers

Deployment of various services

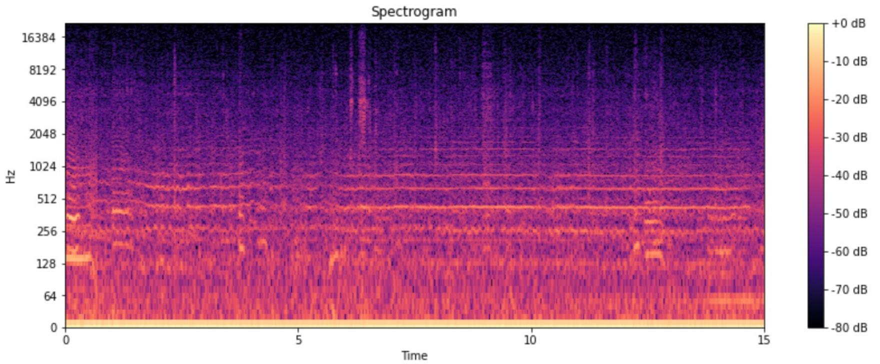
(a) Bees staying around the entrance (Lyon Hive #3)

(b) Bees bringing back pollen (Lyon Hive #3)

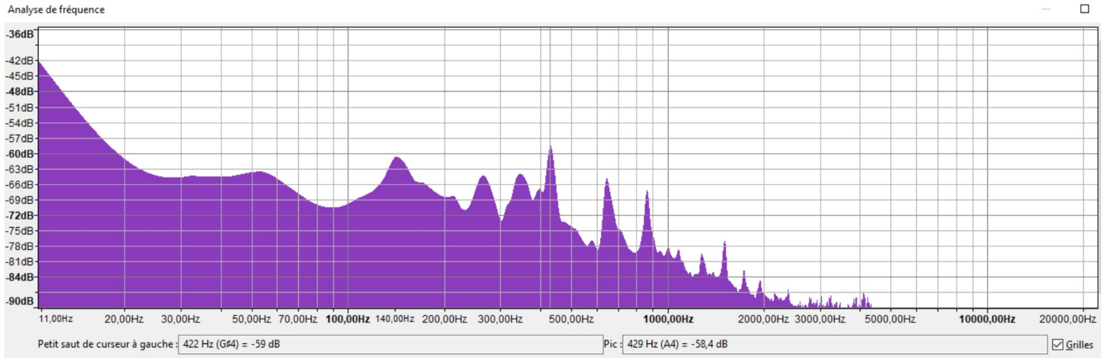
(c) A wasp prowling around the hive (Lyon Hive #3)

(d) An Asian hornet prowling around the hive (Cachan Hive #2)

```
plot_log_spectrogram(file_name)
```




```
Image(filename='../data/visite_25_09_2020/analyse/frequency_analysis.png')
```



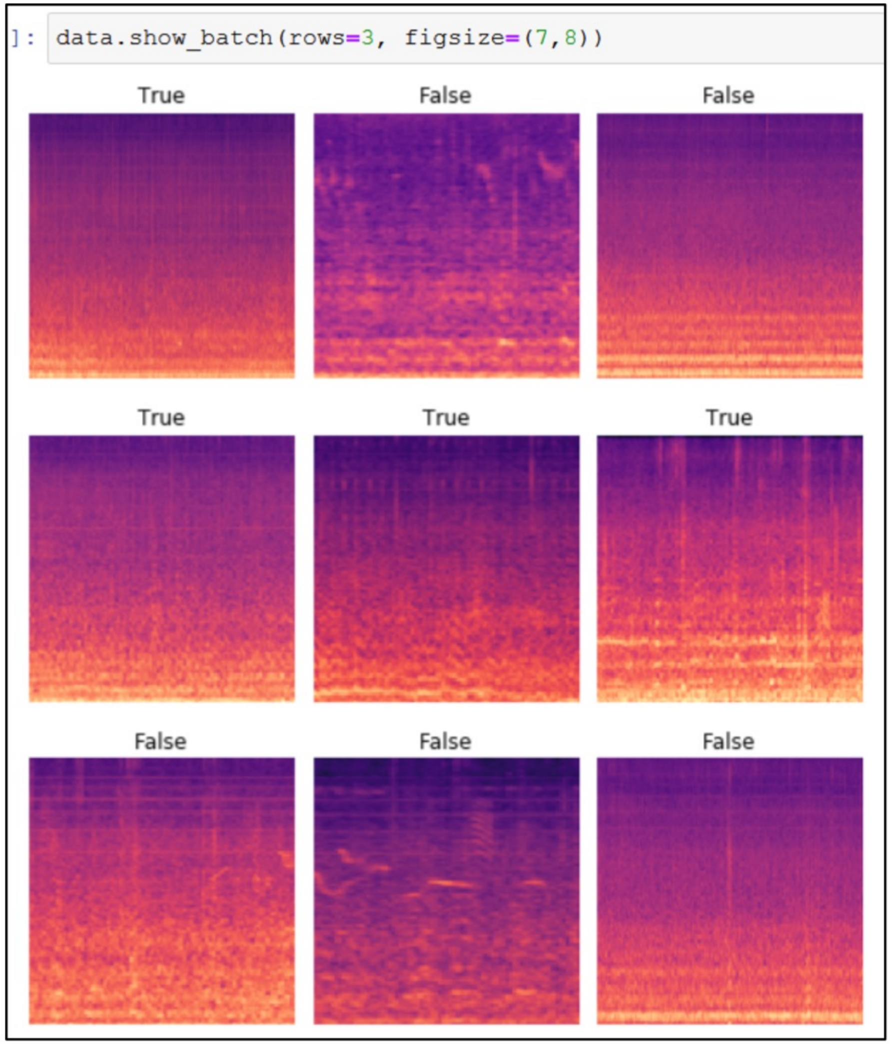
Log-spectrogram of a 15-second in-hive audio sample & Dominant sound frequencies of a 15-second in-hive audio sample

As an example, use sound data to **detect the presence of the queen** thanks to energy-managed sound classification algorithms.

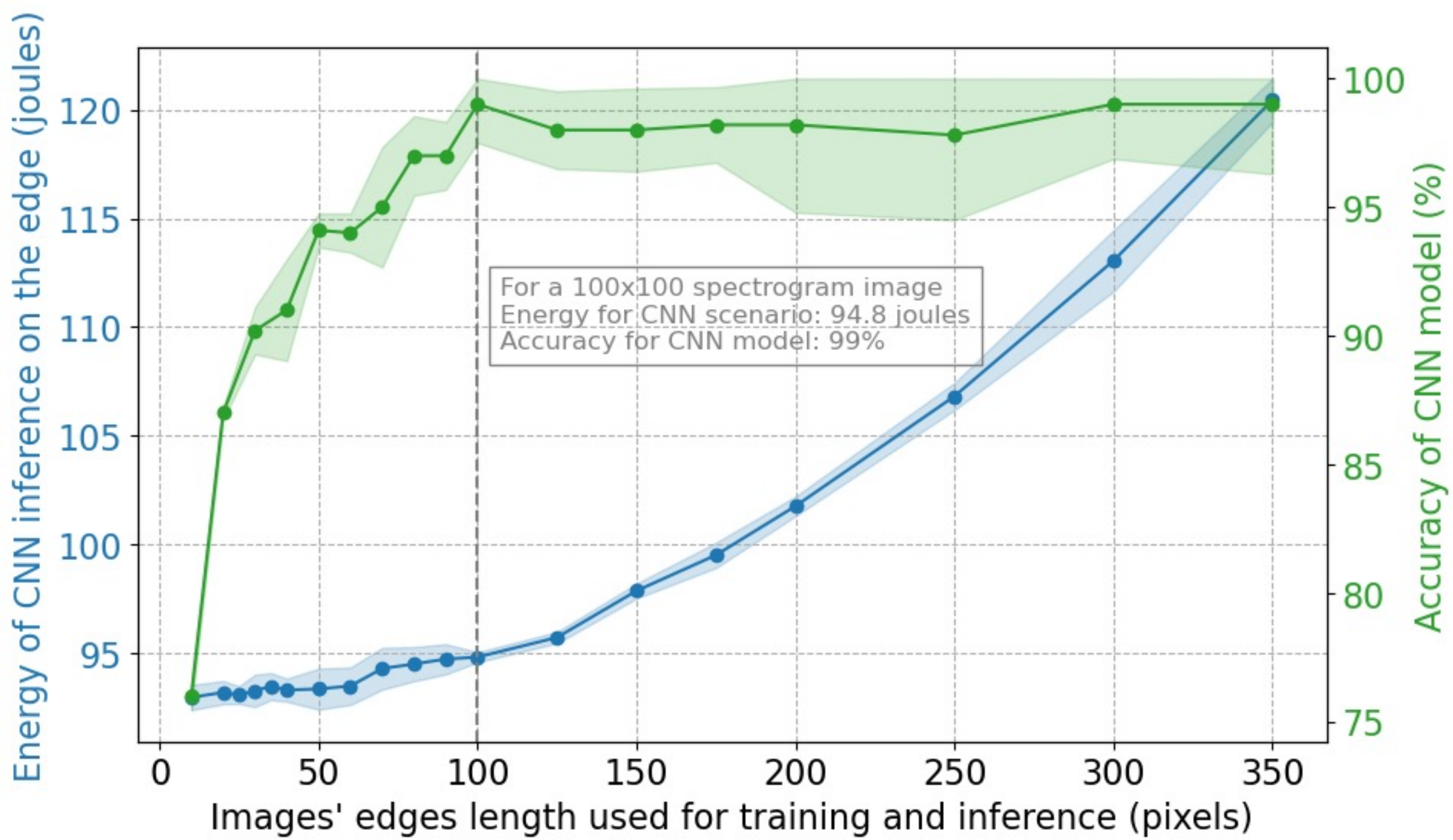
AI Models

- Using data from: Nolasco, I. et al., *Audio-based identification of beehive states*. CoRR, abs/1811.06330.
- Sound classification model using a deep convolutional neural network (ResNet34) to **determine the presence/absence of the queen bee.**

```
# Loading data (csv file containing paths to images)
data = (ImageDataBunch
        .from_csv(path,
                  folder=".",
                  csv_labels='labels_train_valid_queen.csv',
                  label_col=1,
                  ds_tfms=tfms,
                  size=224,
                  num_workers=4)
        .split_by_folder(train='train', valid='valid')
        .databunch()
        .normalize(imagenet_stats))
```



Energy of CNN model execution and its accuracy on the test set as a function of training set's images' size



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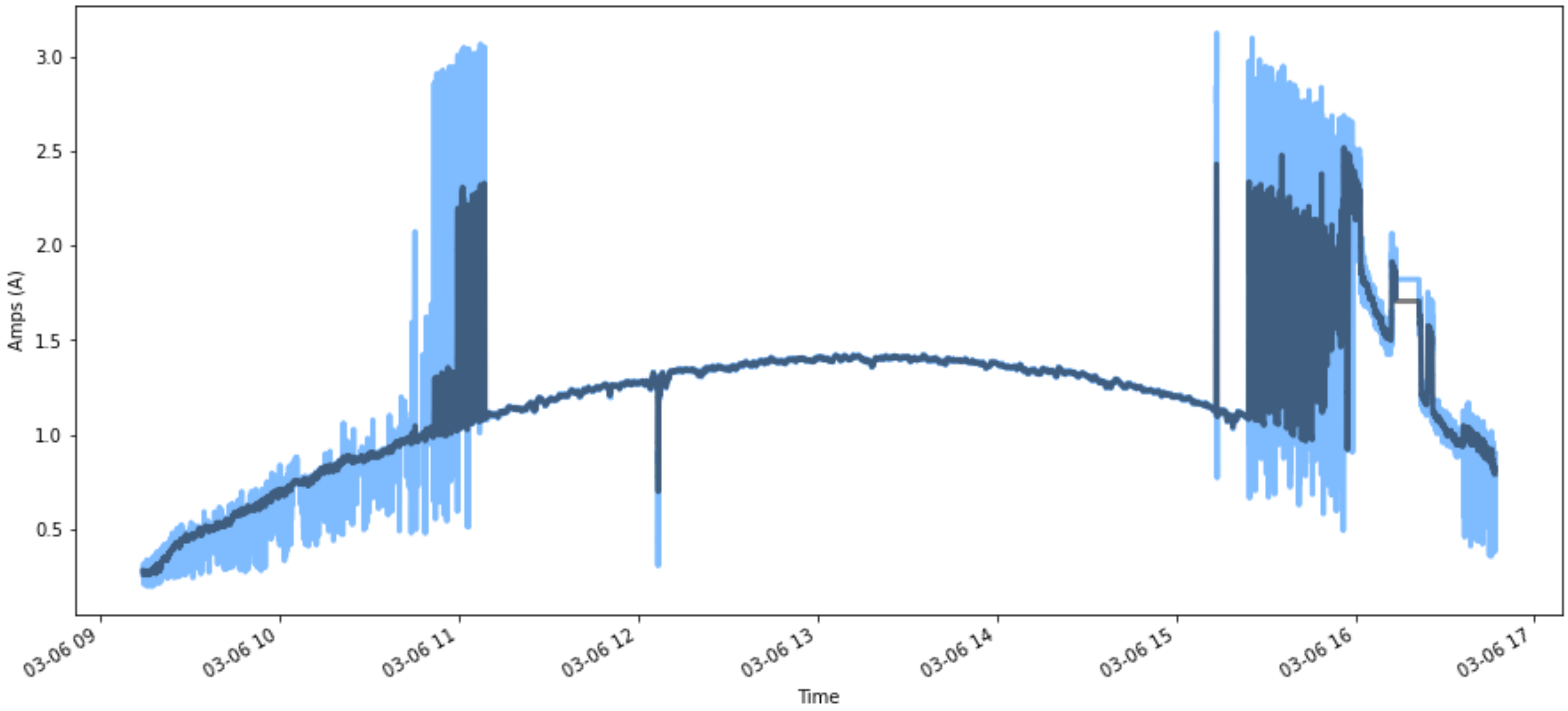
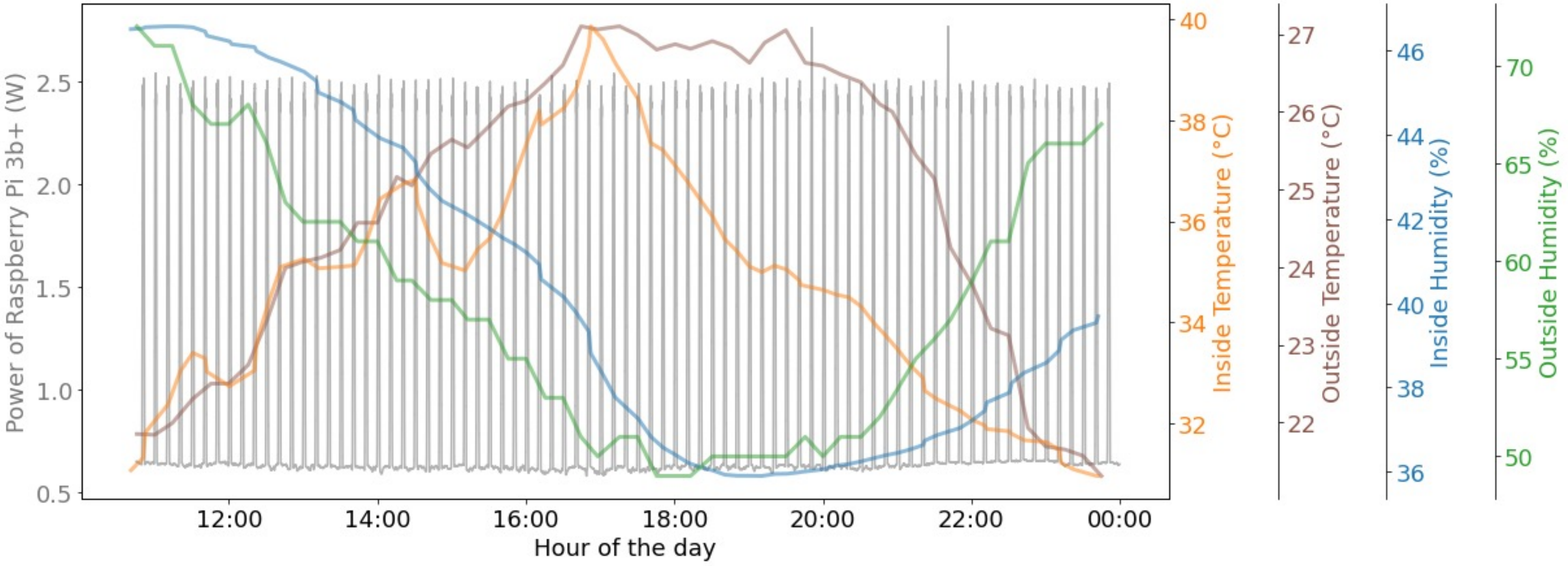
Solar production

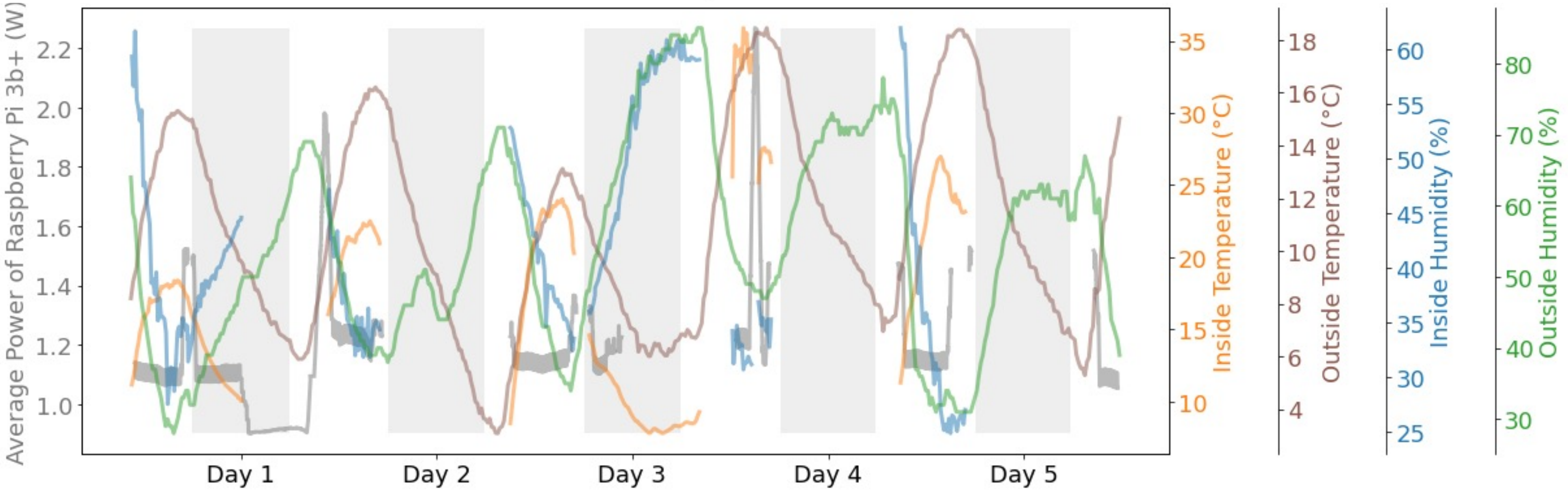


Progress of solar production over the course of one day

Environmental and energy collected data on one day/week….



Summer 2022



Ligh gray = night

Spring 2022

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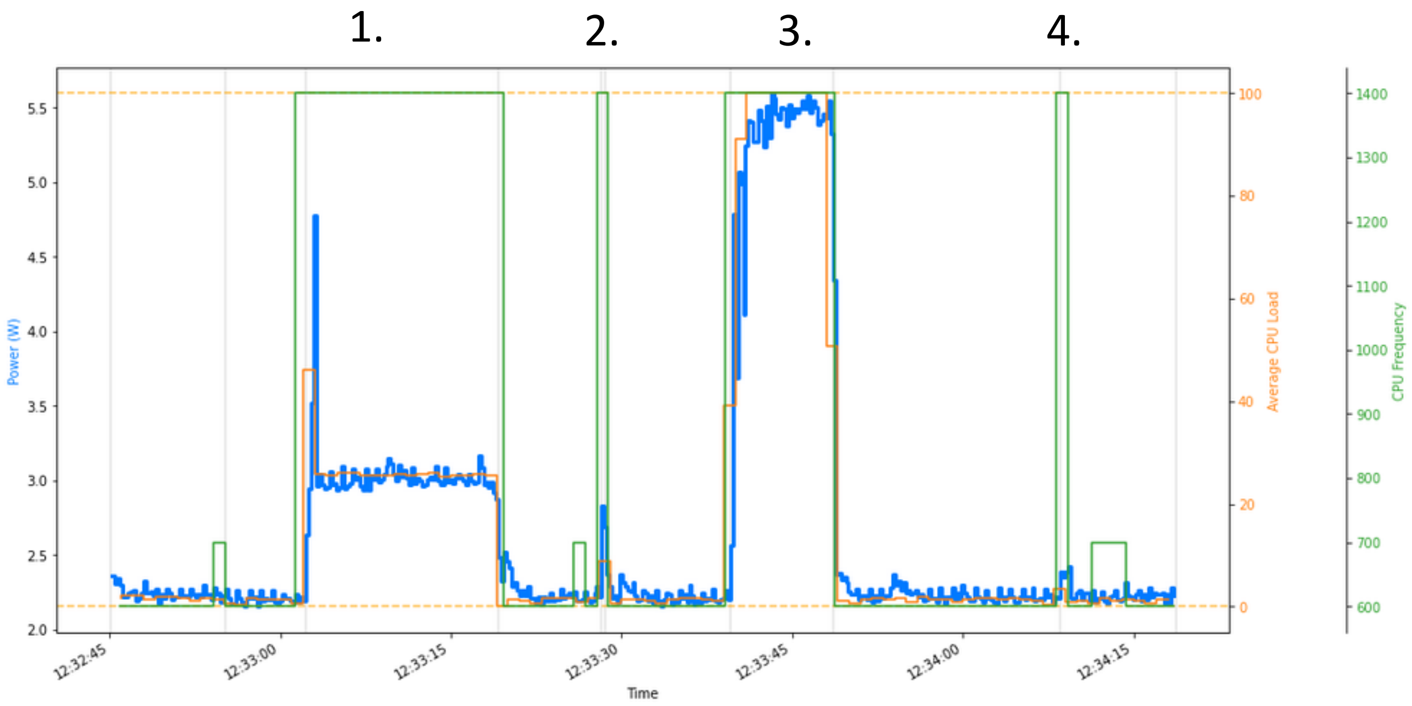
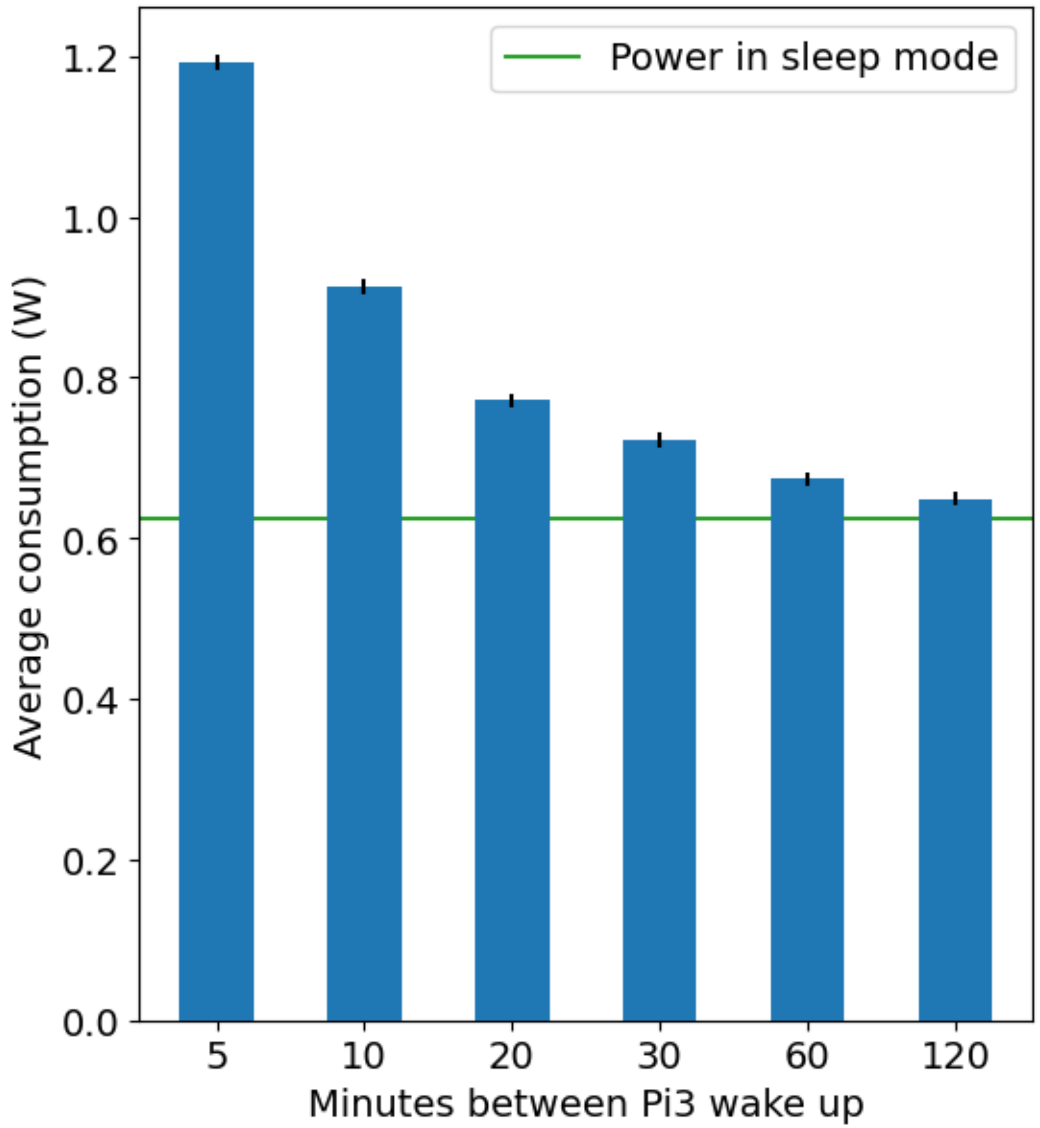
Energy measurements of queen detection service

- Raspberry Pi deployment
- Collection of the energy, step by step:
    1. Audio recording
    2. Conversion into spectrogram
    3. Loading AI model
    4. Prediction




```
Time elapsed: 93.34s
Average power: 536.42mA
Energy consumed: 250.35J
Std Dev. Energy consumed: 185.09mA
```

Energy differences



Energy costs of AI on Edge

Edge Task	Energy of Edge (joules)	Time (seconds)
	Scenario: Edge (SVM)	
Sleep	111.6	178.5
Wake up & Data collection	131.8	64.0
Queen detection model (SVM)	98.9	46.1
Send results	3.0	1.5
Shutdown	21.0	9.9
Total	**366.3 joules**	**300 seconds**
	Scenario: Edge (CNN)	
Sleep	116.9	187.0
Wake up & Data collection	131.8	64.0
Queen detection model (CNN)	94.8	37.6
Send results	3.0	1.5
Shutdown	21.0	9.9
Total	**367.5 joules**	**300 seconds**

SVM : Support Vector Machine
CNN : Convolutional Neural Network

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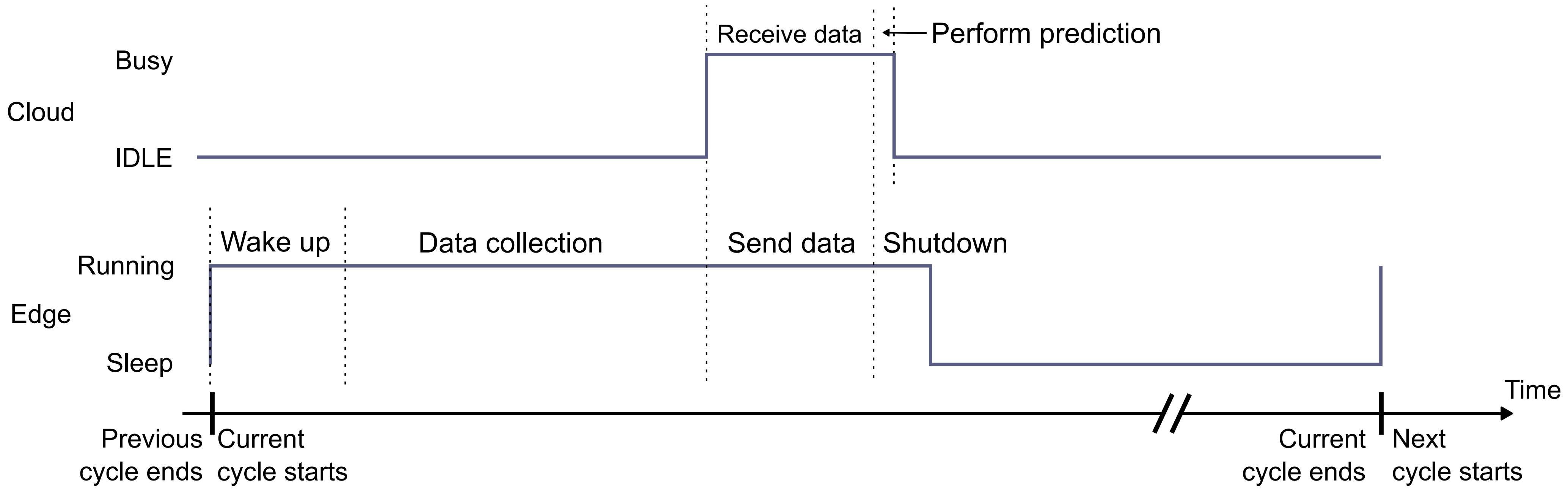
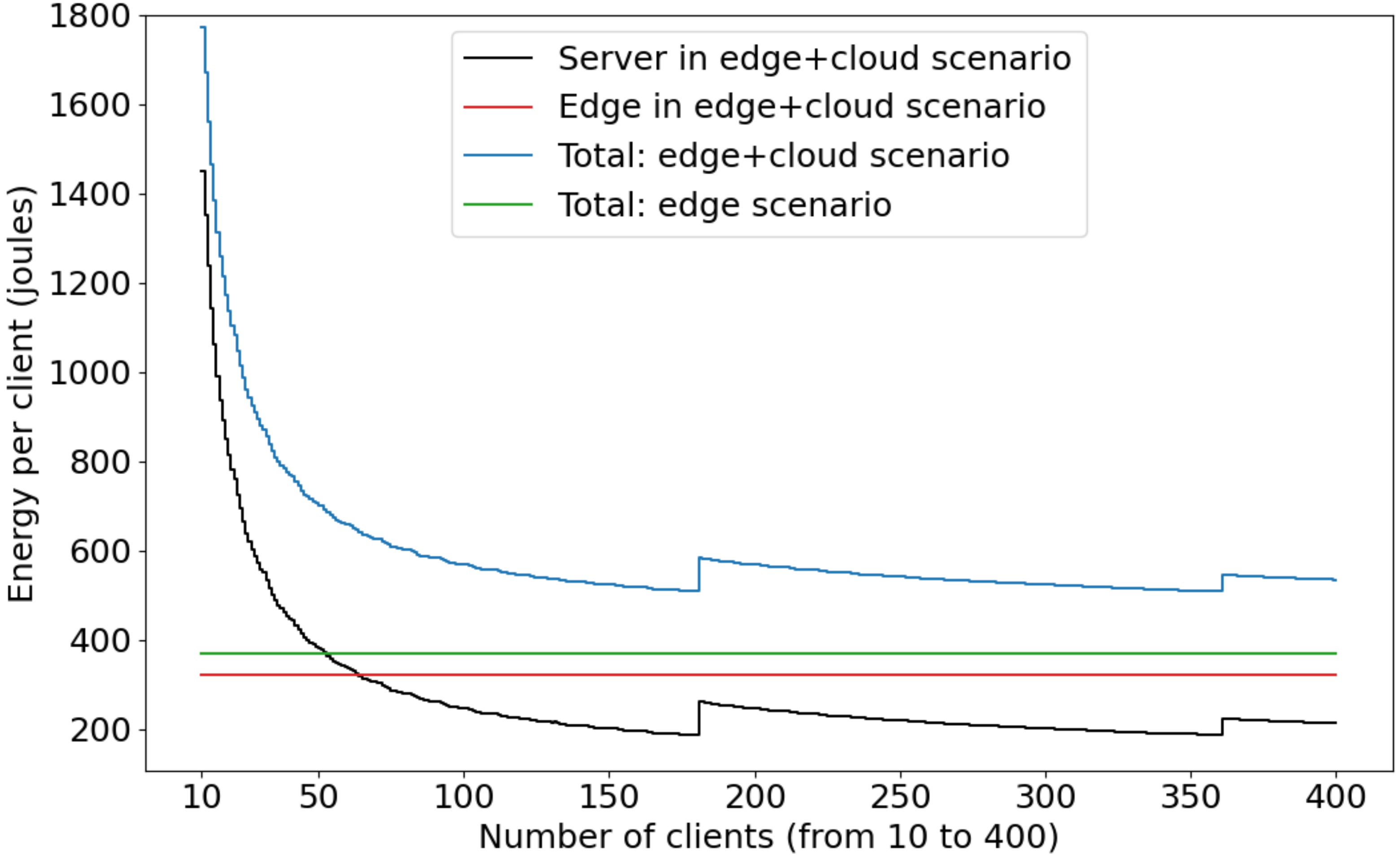
Energy cycles with Edge+Cloud support



Energy costs of AI on Edge + Cloud

Edge Task	Energy of Edge (joules)	Cloud Server Task	Energy of Cloud Server (joules)	Time (seconds)
		Scenario: Edge+Cloud (SVM)		
Sleep	131.9	Idle	9415	211.1
Wake up & Data collection	131.8	Idle	2854	64.0
Send audio	37.3	Receive audio	1032	15.0
Shutdown	0.2	Queen detection model (SVM)	6.3	0.1
Shutdown	20.8	Idle	437	9.8
Total	**322.0 joules**		**13744.3 joules**	**300 seconds**
		Scenario: Edge+Cloud (CNN)		
Sleep	131.9	Idle	9415	211.1
Wake up & Data collection	131.8	Idle	2854	64.0
Send audio	37.3	Receive audio	1032	15.0
Shutdown	2.1	Queen detection model (CNN)	108	1.0
Shutdown	18.9	Idle	397	8.9
Total	**322.0 joules**		**13806 joules**	**300 seconds**

Results in ideal theoretical scenario

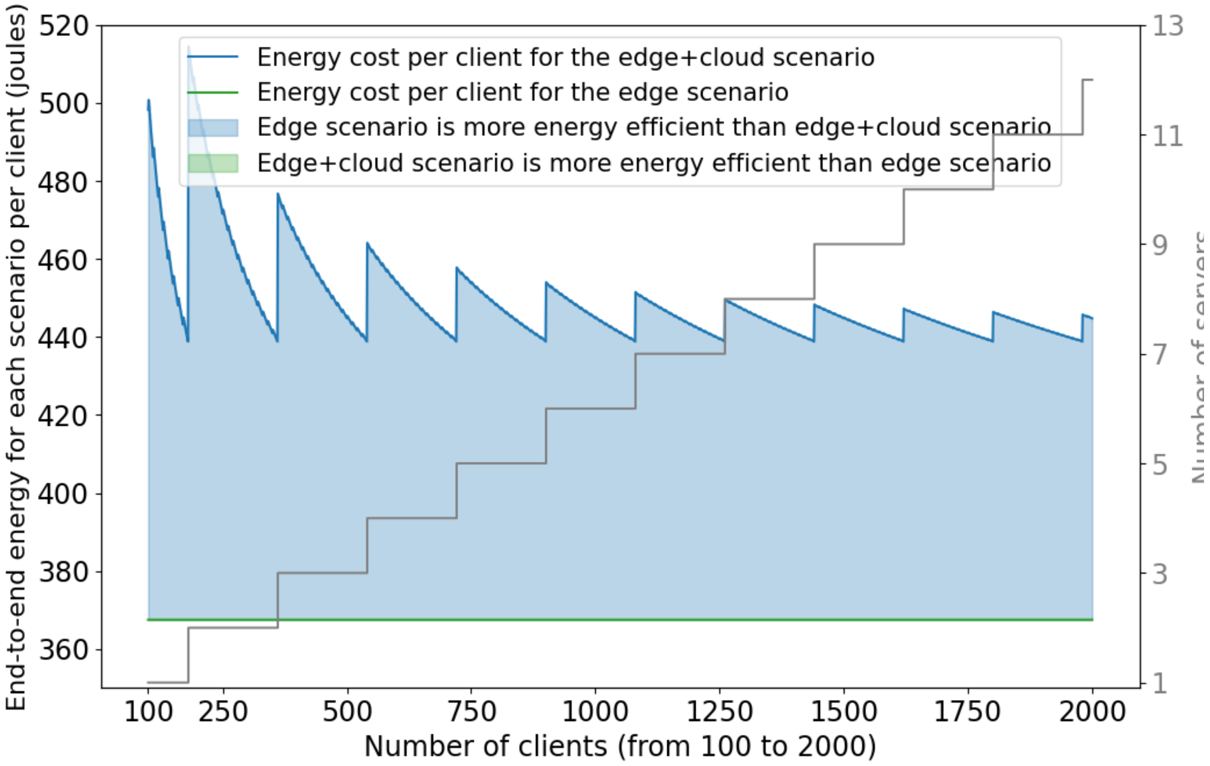


The server's overall energy consumption per client converges towards 116 joules (energy when all server's time slots are full).

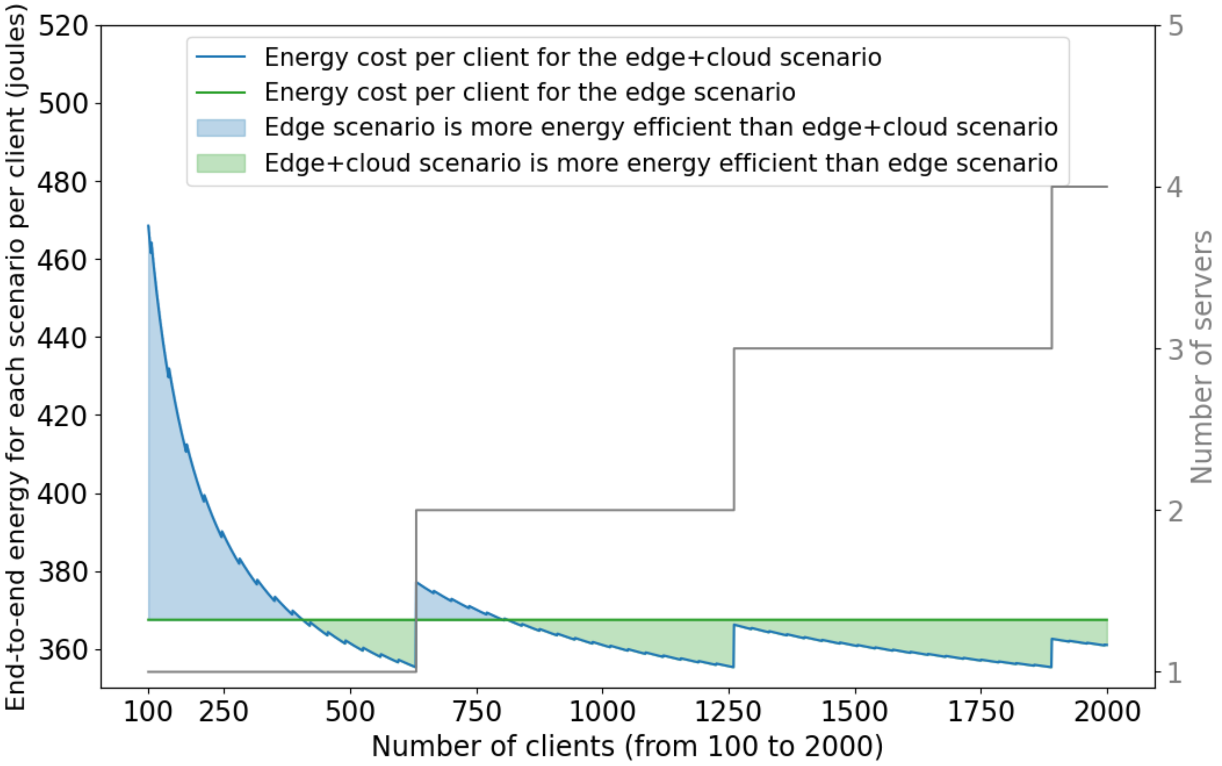
The smart beehive case brings the overall best cost per beehive (shown in blue) to 116 + 322 = 438 joules

Edge wake-up frequency : 5 minutes - Number of clients allowed in parallel in time slots: 10

Benefits of cloud server ? End2End energy costs



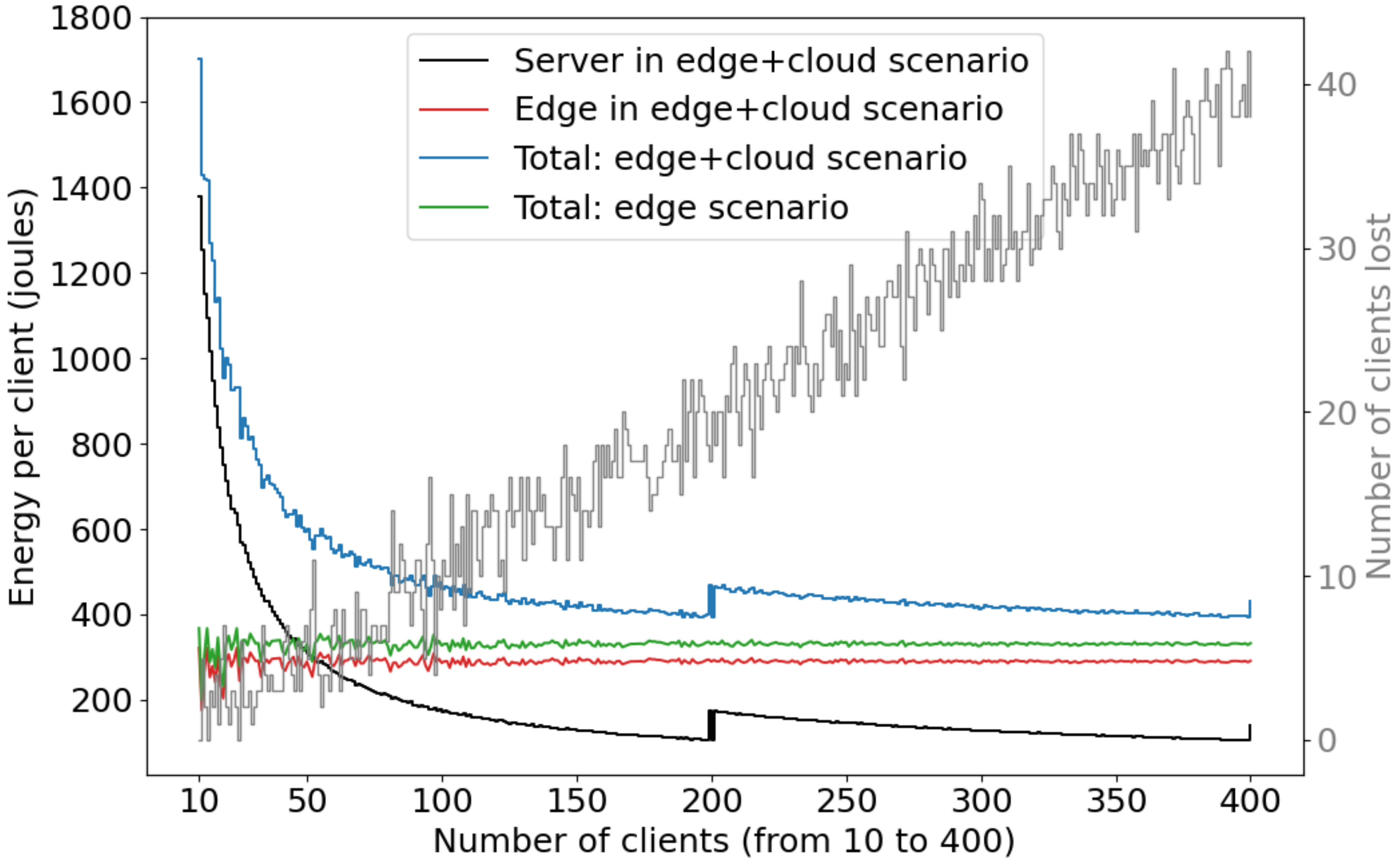
Number of clients allowed in parallel : 10 per time slot



Number of clients allowed in parallel : 35 per time slot

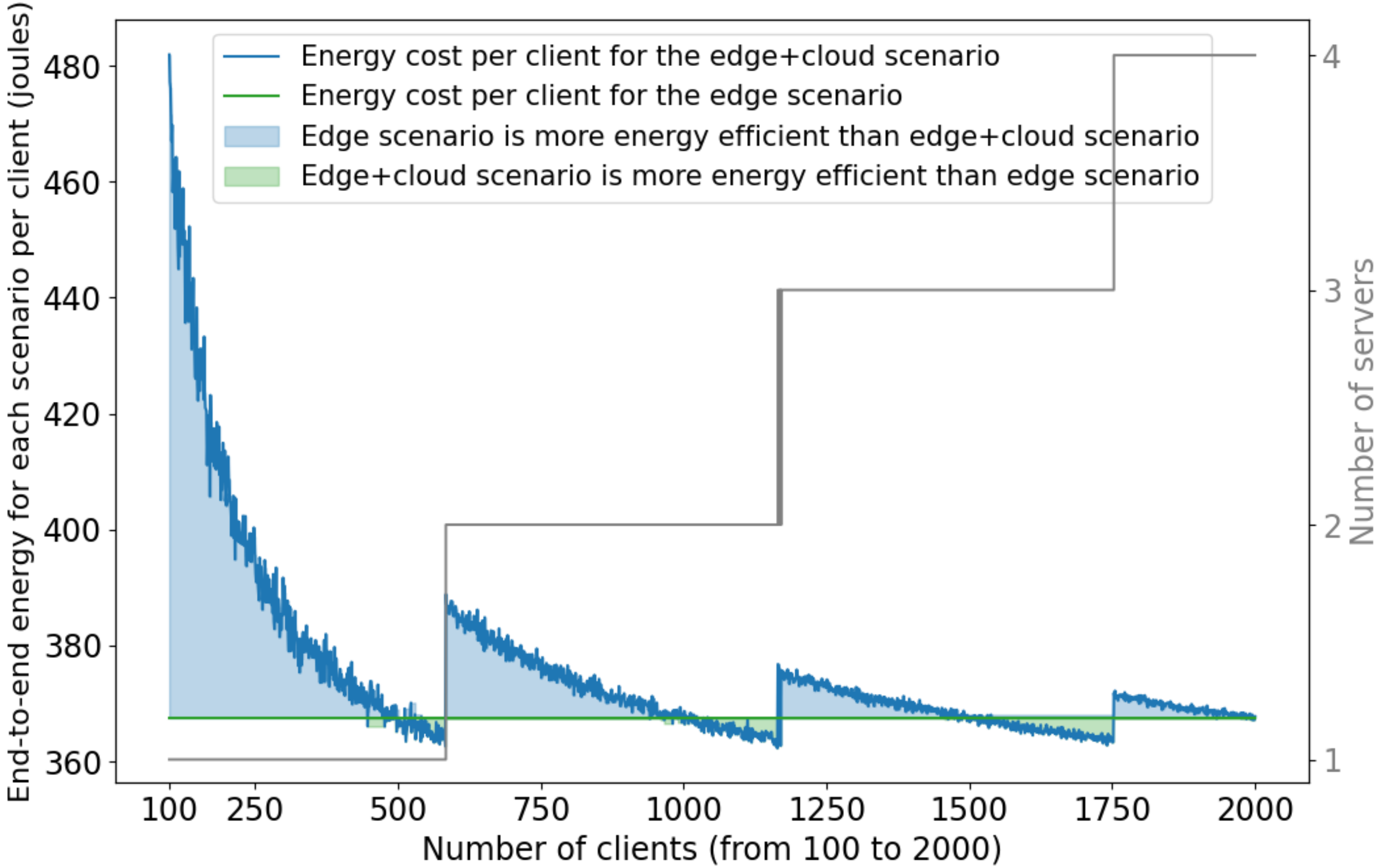
406 clients needed for edge+cloud scenario more energy-efficient
Maximum difference edge+cloud scenario is 12.5 joules at 630 clients
Above 803 clients, the edge+cloud scenario is more energy-efficient than the edge scenario

Comparing loss of clients and cloud servers



Exploring scenario of loss : example of loss of clients at every wake-up time. A random Gaussian distribution (mean: 10% of the total number of clients; standard deviation: 2) is used to draw the number of lost clients.

End2End energy



Compared to ideal scenario, Cloud benefit is not always the case

Comparison of end-to-end energy per client for the two scenarios with different server settings and with loss. Number of clients allowed in parallel in time slots: 35.

Conclusion & Future works

- When energy budget is so limited -> hunting the joules is mandatory
- Cloud infrastructures become relevant when number of connected beehives increase (but not always) – hypothesis :same service
- Sharing data collection and datasets : https://zenodo.org/record/7880085#.ZGdeL9bP1Yg

- Yet to come:
  - Take into account of smart beehive + cloud servers full cycle and not only energy considerations
  - Large scale emulation of all beehives in France (around 2 Millions) -> optimizing services to beekeepers and bees

- More to read

  - Hugo Hadjur, Doreid Ammar, Laurent Lefèvre, Toward an intelligent and efficient beehive: A survey of precision beekeeping systems and services, Computers and Electronics in Agriculture, Volume 192, 2022, 106604, ISSN 0168-1699, https://doi.org/10.1016/j.compag.2021.106604
  - Hugo Hadjur, Doreid Ammar, and Laurent Lefèvre. 2020. "Analysis of energy consumption in a precision beekeeping system." In *Proceedings of the 10th International Conference on the Internet of Things* (*IoT '20*). Association for Computing Machinery, New York, NY, USA, Article 20, 1–8. https://dl.acm.org/doi/10.1145/3410992.3411010

Questions ?

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