Evaluating the carbon footprint of an AI program

2022-2023

1 Carbon footprint of a machine learning program

The objective of this session is to study the environmental impacts of an artificial intelligence program.

The Green Algorithms tool enables to compute the electricity consumption and the carbon footprint of executing a machine learning program.

The electricity consumption is computed as follows:

$$C_{total} = runtime \times (\sum_{c \in cores} (P_c \times usage_c) + P_{memory}) \times PUE \times PSF$$

with:

- $runtime$ the runtime in $hours$
- P_c the power draw of a core c (CPU or GPU) in $Watt$. The actual power draw being unknown, Green Algorithms uses the CPU or GPU TDP, which is considered to be an estimation of the average power draw for the equipment.
- $usage_c$ the use rate for core c, between 0 and 1
- P_{memory} the power draw of the memory
- PUE the power usage effectiveness of the datacenter, over 1. By default, the PUE is the average global PUE: 1,67.
- PSF is the number of times that the training was done, by default 1

Then the carbon footprint is computed as follows:

$$CarbonFootprint = C_{total} \times CI$$

with:

- CI the carbon intensity of the electricity from the region considered

We consider the training parameters in table 1.

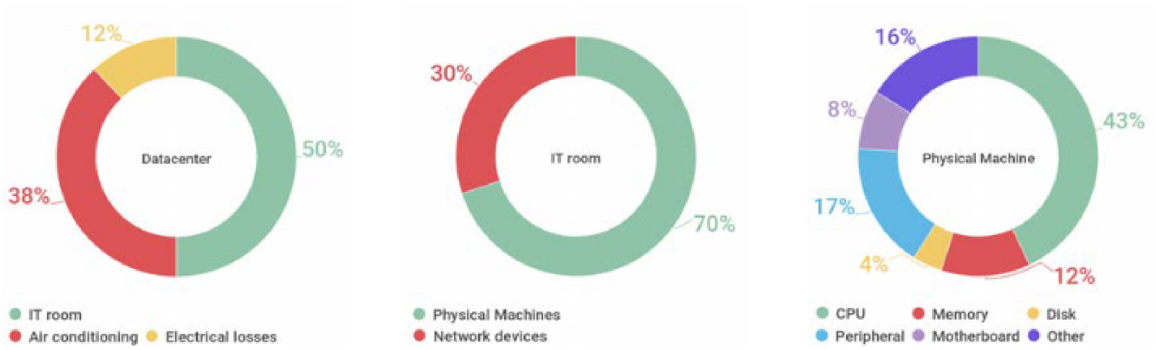
In the following questions, you will use Green Algorithms.

1. Calculate the electricity consumption and the carbon footprint associated with the reference scenario.

on default PUE= 1.67 405.41 kWh, 20.79 kg CO2e

Runtime	190 h
Number of CPUs	4
Type of CPU	Xeon E5-2683 v4
Number of GPUs	4
Type of GPU	Tesla V100
Memory available per GPU	32GO
Location of the server	Orsay, France

Table 1: Information about model training



(a) Average energy consumption distribution of 94 datacenters from 2006 to 2015 [59].

(b) Energy consumption distribution in the IT room [60].

(c) Energy consumption distribution at the PMs level [60].

Figure 1: Distribution of electricity consumption in data centers. Physical machines = servers. Source: David Guyon, 2018

2. The default PUE is 1.67. How does the carbon footprint change if you use a datacenter with a PUE of 1.2? (reset the PUE to its default value afterwards) for PUE=1.2, 14.94 kgCO2e \ carbon footprint grows with the growth of PUE

3. As a reminder, the PUE is calculated as follows:

$$PUE = \frac{total\ consumption\ of\ datacenter}{IT\ equipment\ consumption}$$

A significant portion of a data center's non-IT consumption comes from air conditioning. What does this tell you about the relevance of using an average PUE?
the location really matters, not only because of the source of electricity, but also the local climate...

4. If we assume that the electricity consumption of the datacenter follows the distribution of Figure 1, what proportion of the electricity consumption has been studied with Green Algorithms? (be careful however because in this figure, there are only CPUs so it is not really transposable to our study case)
The Green Algorithm calculate the the CPU+Memory part of figure C of PMs part in figure B of IT room part in figure A

5. What advantages and disadvantages do you see in using such a tool rather than a python package like CodeCarbon?
ADVANTAGE: quick and easy to try some example data, and quick to get default visualization. DISADVANTAGE: optional parameters of the function is rather fixed, and not that easy to use it for large-scale data processing and analyse

2 Taking into account the life cycle of equipment

1. If we assume that the distribution of the carbon footprint of the servers in the datacenter follows the distribution of Table 2, what proportion of the carbon footprint was studied with Green Algorithms?

approximately 74.27%

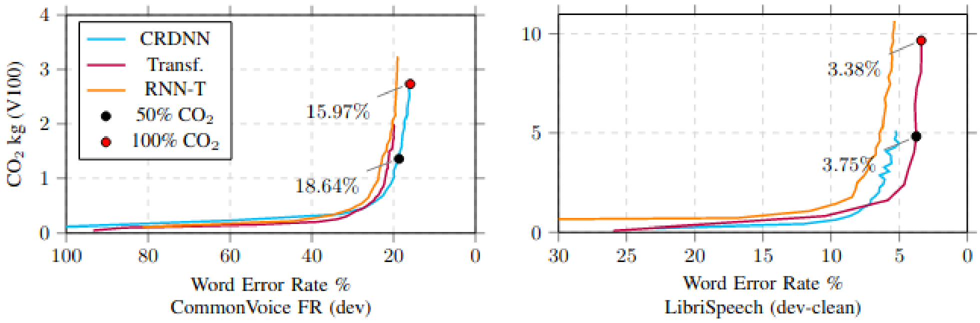


Figure 2: *CO_2 emitted in kg (in France) by different E2E ASR models with respect to the word error rate (WER) on the dev sets of LibriSpeech and CommonVoice. The curves exhibit an exponential trend as most of the training time is devoted to slightly reduce the WER. The black and red dots indicates the WER obtained with* 50% *and* 100% *of the emitted CO_2. On LibriSpeech,* 50% *of the carbon emissions have been dedicated to reach SOTA results with an improvement of* 0.37%.

Figure 2: Error rate vs carbon footprint. Source : T. Parcollet et al, 2021

2. How do you think the carbon footprint changes if the servers are on a cloud rather than local? Test your hypothesis with an Azure cloud in "France Central" to have a similar location. on cloud 14.94 CO2e 291.31 kWh, compared to 20.79 CO2e on local server, cloud computing will cause less carbon footprint
3. Does the comparison of cloud vs local servers with Green Algorithms allow to conclude on the environmental interest of the cloud compared to local servers?
no, becuase the actual energy source, the cooling systems, the hardware efficiency can be different
4. Compare the resulting footprint with an older model (NVIDIA P100 for example, from 2016) and a newer, more specialized model (TPU v3 for example, from 2018). What do you conclude?
on cloud, P100 11.81 CO2e, V100(newer) 14.00 CO2e, TPUv3 9.62 CO2e, The type of hardware influence the footprint
5. What information would you need to estimate the carbon footprint including equipment manufacturing? raw material extraction (if not inclueded in manufacturing part), transport, use, end of life, and if more precise, the recycled and recovered part

Equipment	gCO2e	%
Computation servers (manufacturing)	1.16	29
Other servers (manufacturing)	0.38	10
Computation servers (usage: électricity)	1.79	45
Other servers (usage: électricity)	0.64	16

Table 2: Carbon foorprint of servers in the GRICAD infrastructure, for one hour.core of computation. Source: Berthoud et al, 2020

3 Carbon footprint / accuracy trade-off

1. If we had stopped training after 3 days, how much emissions would we have saved?
if stop training for 3 days on the default local server, save 5.41kg CO2e
2. Consider Figure 2 which presents the error rates during training of speech recognition systems for two different corpora (datasets). The authors of the corresponding paper calculated the error rates of the systems when 50% and 100% of the final carbon footprint was emitted. What are the accuracy gains for each curve? When do you think it is reasonable to stop training such a system?
the carbonprint grows with the growth of ML model accuracy, especiallym when go beyond a certain acurracy ratem the CO2e growth will go exponential. So the core idea of green ML is to stop before the exponential growth of CO2e. To trade off with the model accuracy, for Common Voice FR set, stop training between 30%-20% WER, for LibriSpeech model stop between 5%-7.5% will be the most green

4 Training vs inference

Here we will consider the recently created BLOOM language model. Information about training and inference is available in table 3. We will assume that the PSF of the training is 2, and that the CPU consumption is negligible.

1. Calculate the carbon footprint of running this model.

   40.65 T CO2e

2. At the time of writing, the model had been in use for about 18 days, with the consumption of using the model emitting about 19kgCO2e per day. What is the associated carbon footprint for inference? 342 kg CO2e

Runtime	118 days (2 832 hours), 5 hours, 41 min
Number of GPUs	416
Tyoe of GPU	Nvidia A100
Memory available per GPU	80GO (33 280 in total)
Location of the server	Orsay, France
PUE	1.2

Table 3: Information about model training

5 Green or carbon-less electricity?

1. How do you think the carbon footprint evolves if the servers are located in Poland? And in Sweden? Test your assumptions.

in Poland the footprint will be higher for the same computation, in Sweden will be lower, because of the source of electricity

2. According to a Google research paper, Google's renewable energy purchases further reduce the impact to zero [1]. What do you think of this statement?

the "carbon credit zero" of Google means they make their footprint zero by optimizing datacenter's energy consume as well as buy carbon credits. But the current carbon neutral protocal itself is not perfect. For example, trees only last a few decades as carbon sinks, after which they may be burned or decomposed by microbes back into carbon dioxide.

[1] https://arxiv.org/pdf/2204.05149.pdf