Always look on the green side of software

@CoralCalero
@GreenTAlarcos
@GrupoAlarcos
@GreenTICTips

Green Team Alarcos Research Group

Alarcos Research Group

The Enterprise Computing Conference EDOC 2023 Conference

20% GLOBAL **ENERGY** CONSUMPTION IN **2030**

ICT

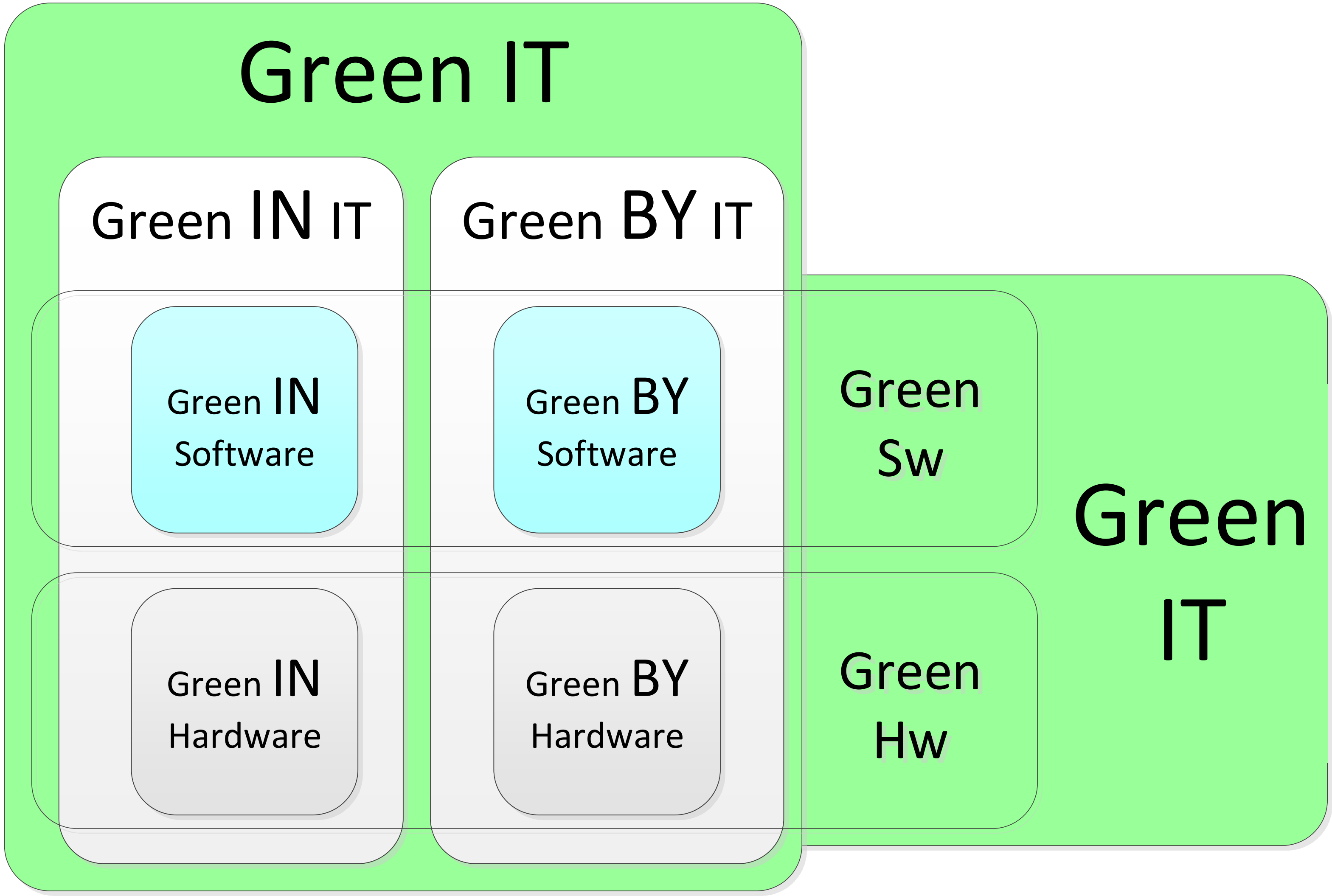
A. S. Andrae and T. Edler, "On global electricity usage of communication technology: trends to 2030”

Green Computing (or Green IT)

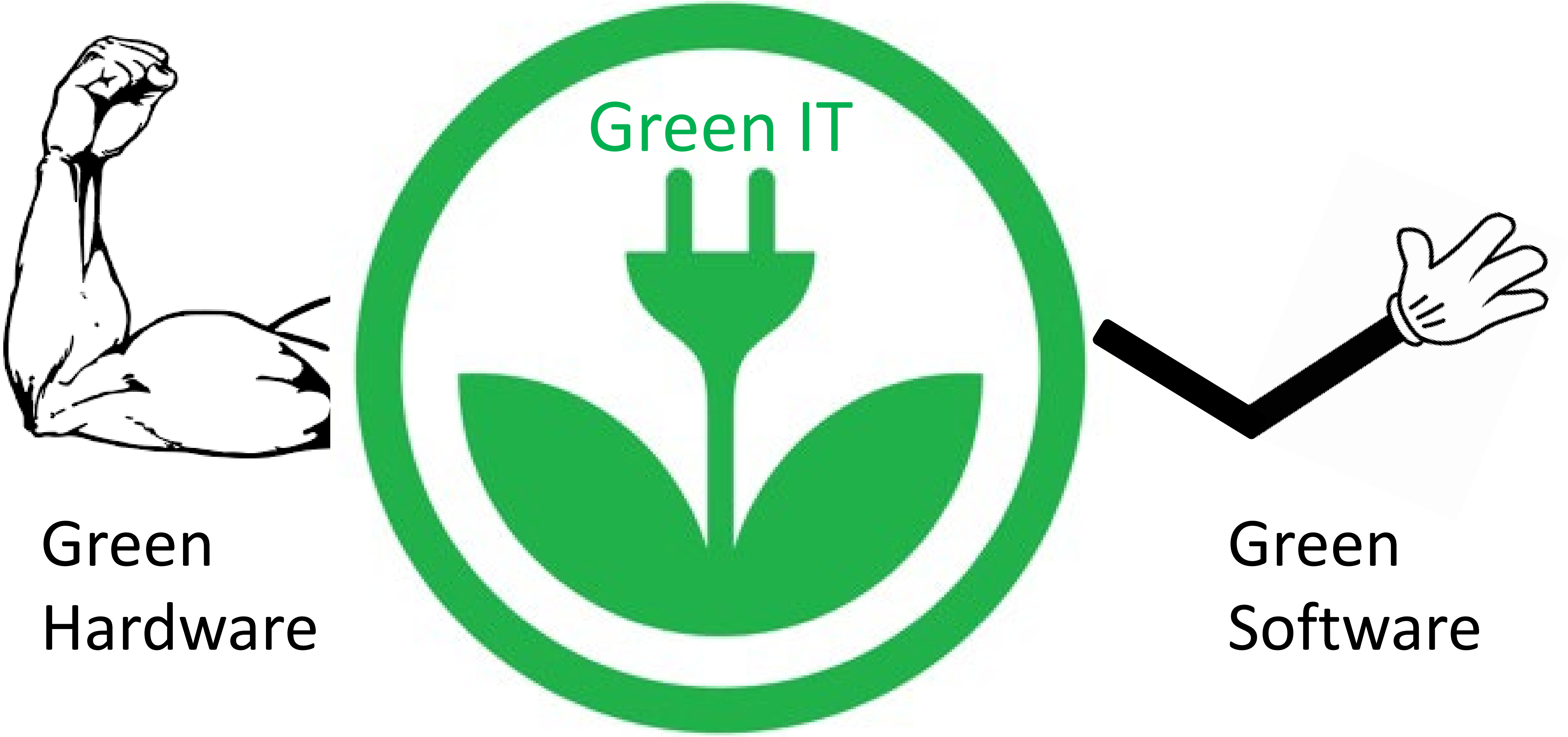
Efficient use of resources, **minimizing** the environmental **impact, maximizing** the **economic feasibility** and **assuring social** duties.

Includes to work on: high consuming **technologies**, environmental **waste**, product **development, computer** recycling, …

Wikipedia



Green IT
Green IN IT
Green BY IT
Green IN Software
Green BY Software
Green Sw
Green IT
Green IN Hardware
Green BY Hardware
Green Hw



Green IT
Green Hardware
Green Software

“Our civilisation is as reliant on software as it is on water”

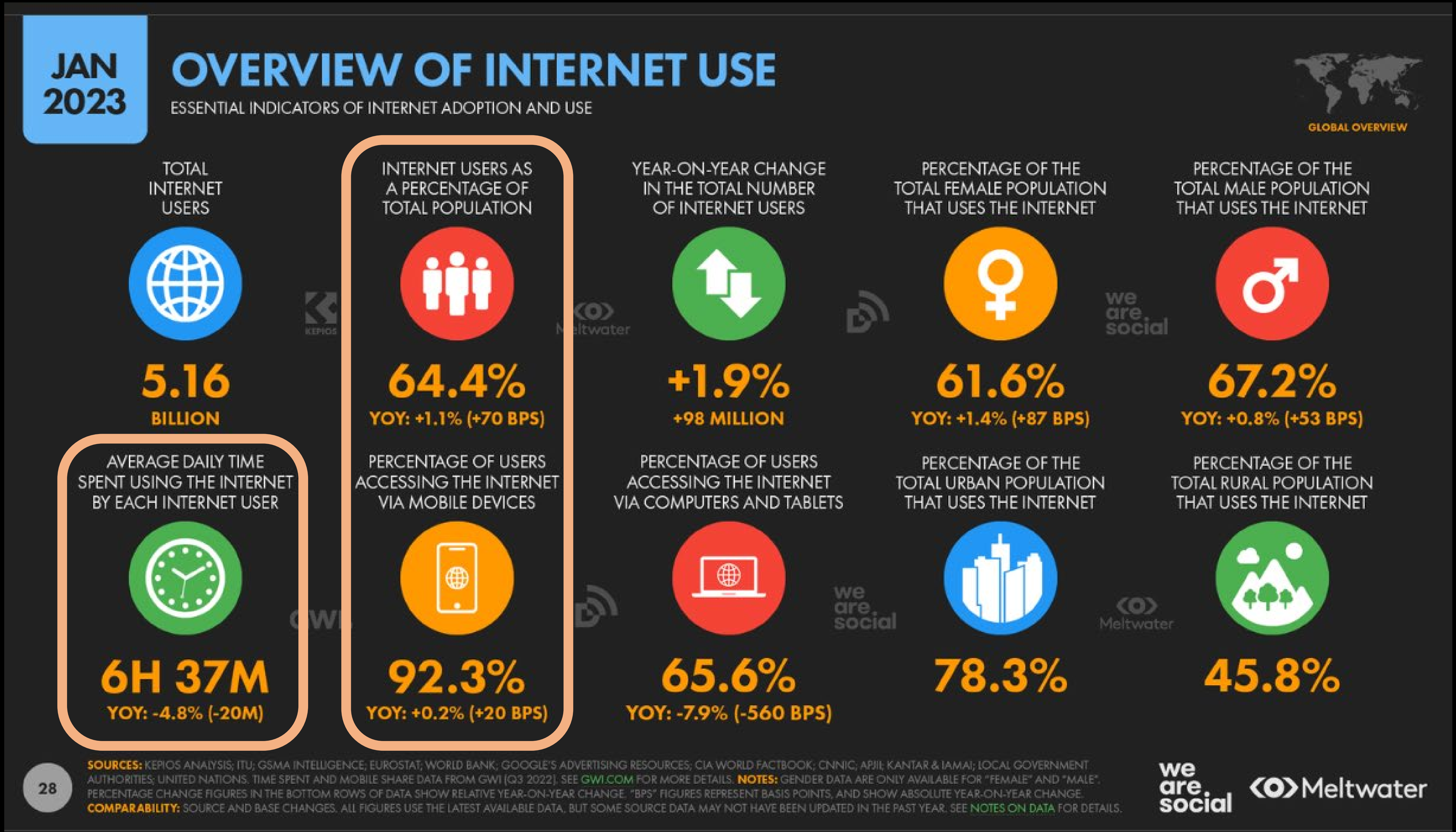
BJARNE STROUSTRUP | the creator of C++

El PAÍS Tecnología. February 5th, 2019

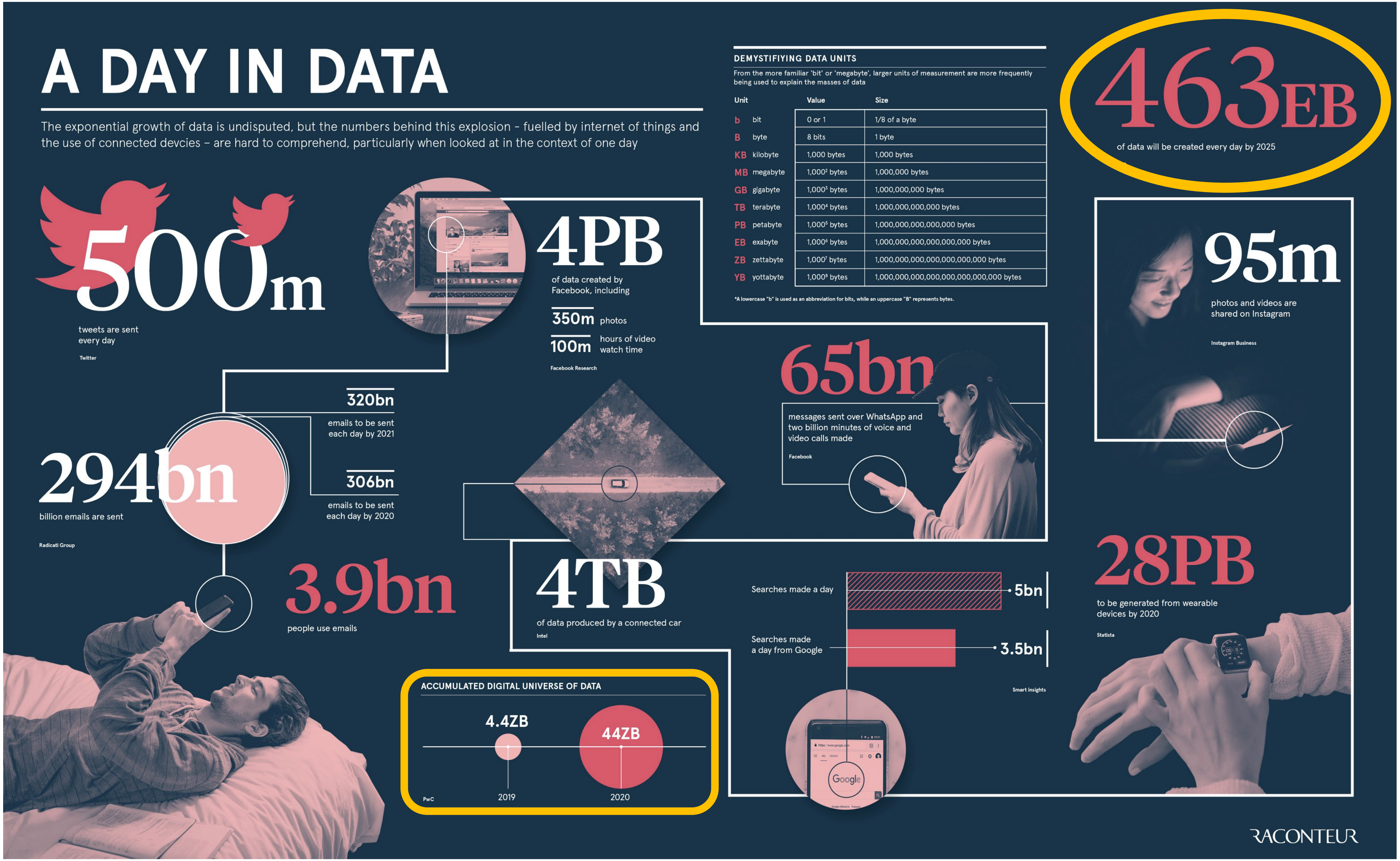
8.000 million people

Most of them with devices using **software**

Internet and mobile devices



Data



A Day in Data - Raconteur

The rising trend of Artificial Intelligence

AI is having a strong **transformative impact** on multiple sectors of activity

Companies are spending nearly **$20 billion dollars** on AI products and services

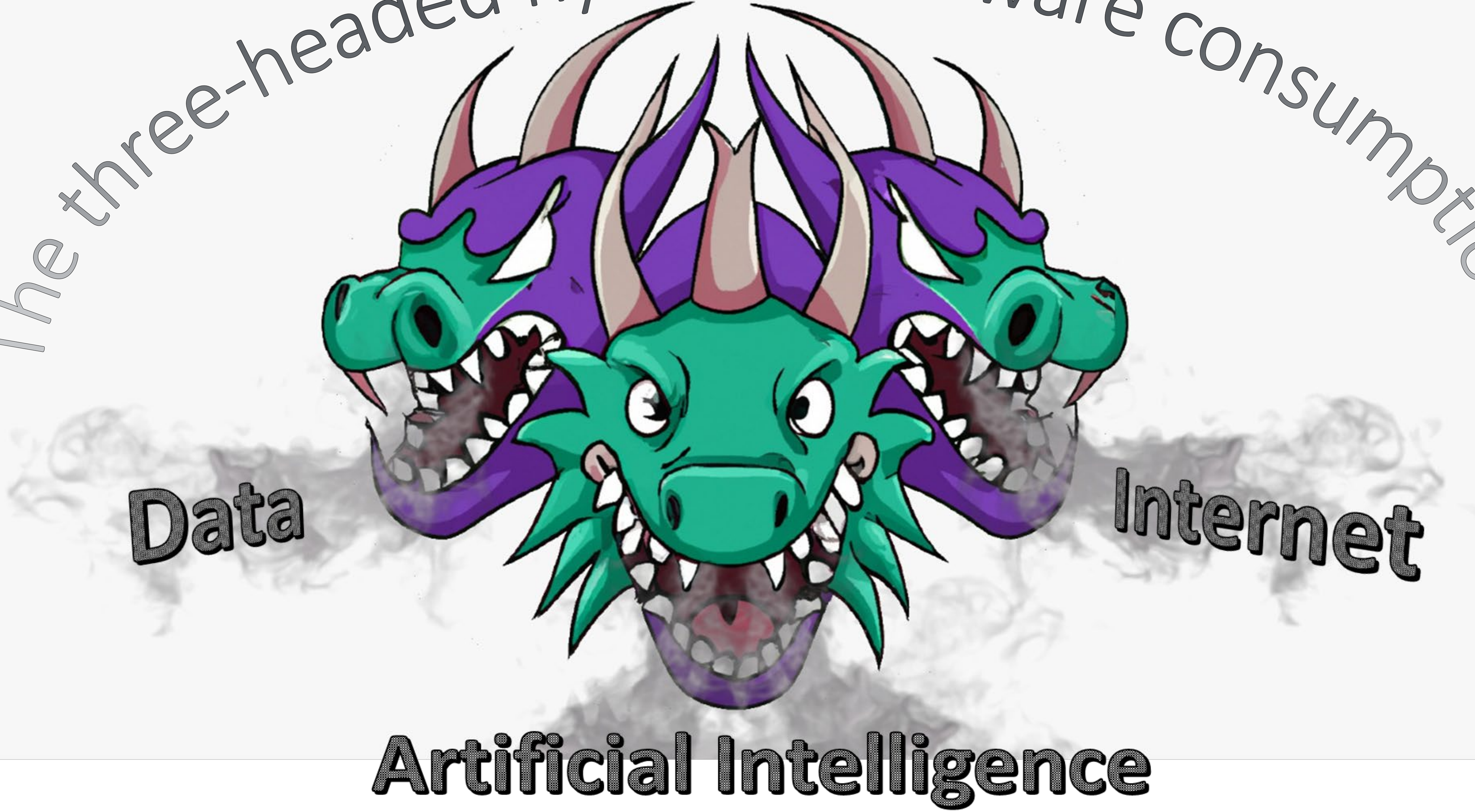
AI is one of the technologies with the **greatest projection and impact** in **all areas** of activity

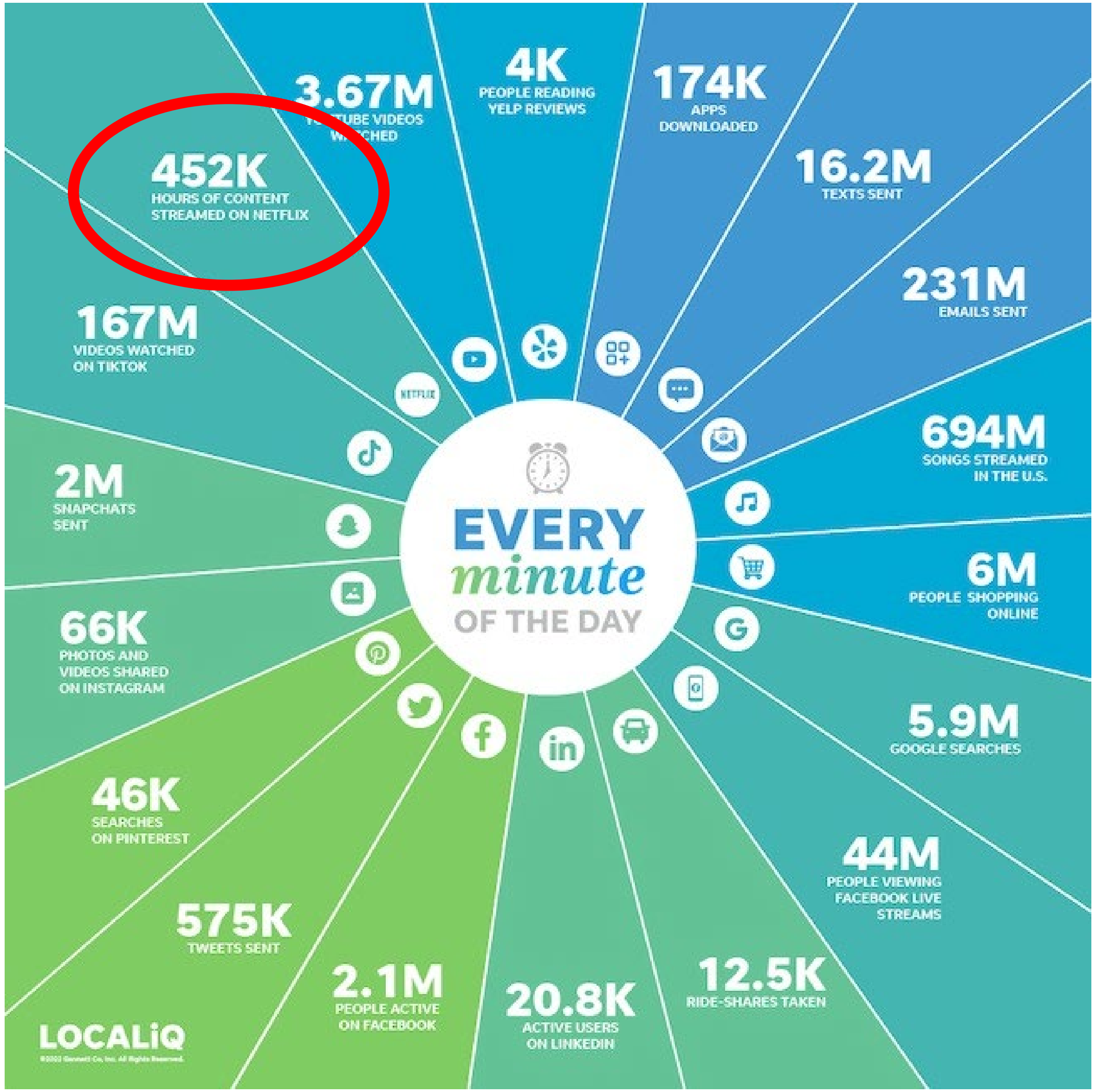
Tech giants like Google, Apple, Microsoft and Amazon spend **billions to create AI** products and services

ENIA A4-RGB largo copia (mineco.gob.es)

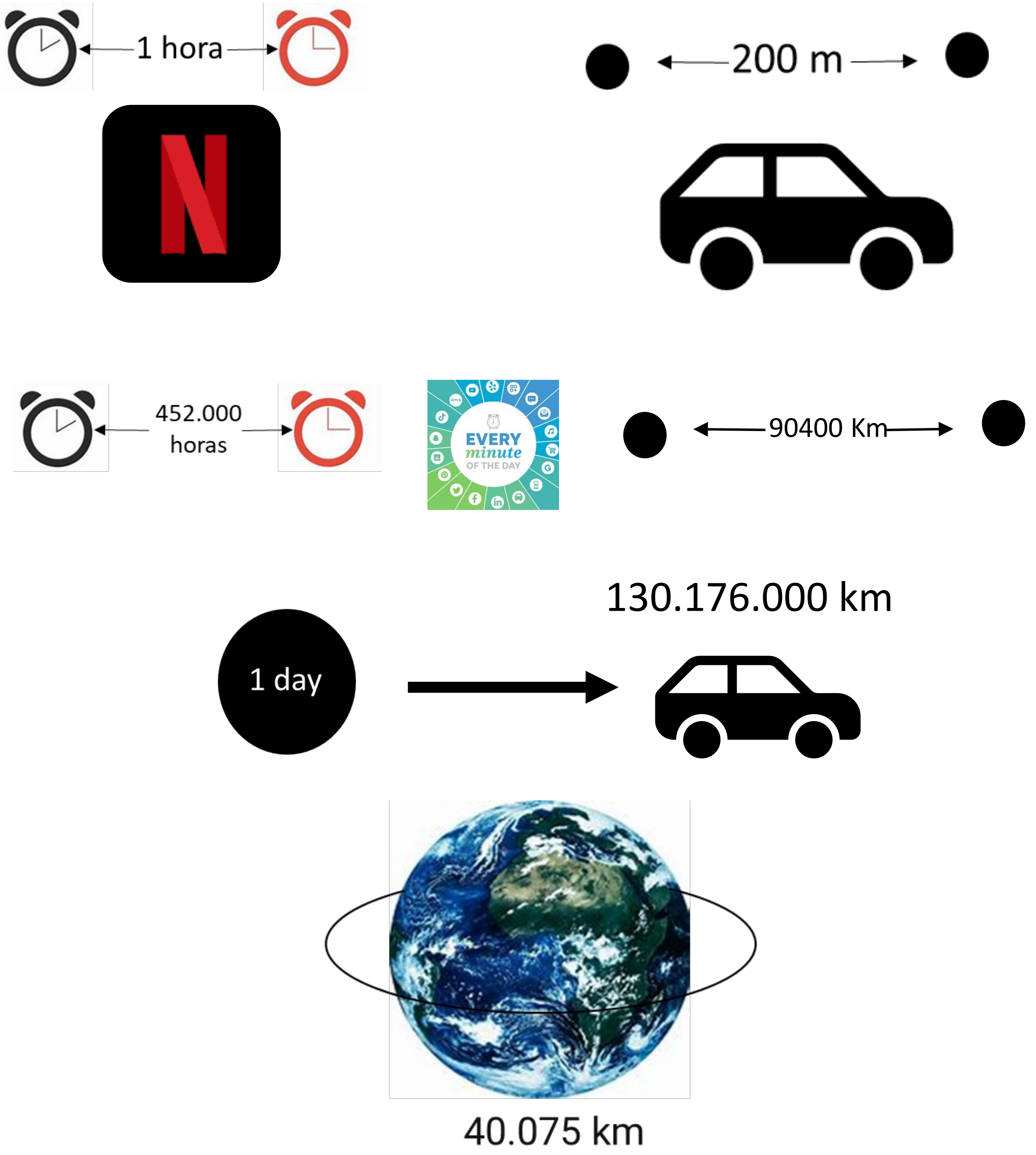
Future of AI: 7 Ways Artificial Intelligence Changes The World | Built In

The three-headed hydra of software consumption





https://localiq.com/blog/what-happens-in-an-internet-minute/



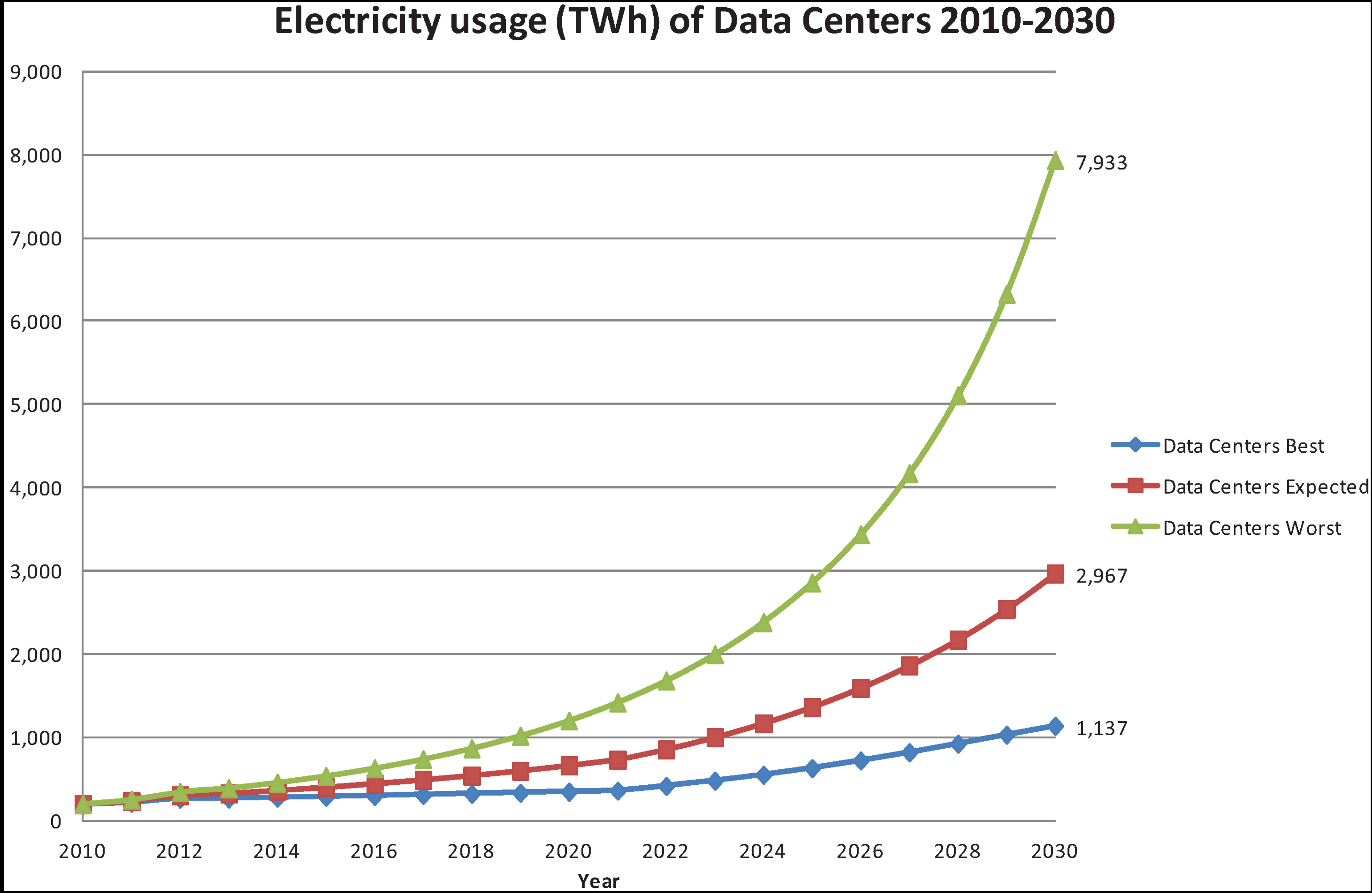
https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines

1 day

3248

https://localiq.com/blog/what-happens-in-an-internet-minute/

https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines



A. S. Andrae and T. Edler, "On global electricity usage of communication technology: trends to 2030”






Strubell et al. (2019) Energy and Policy Considerations for Deep Learning in NLP. https://doi.org/10.48550/arXiv.1906.02243

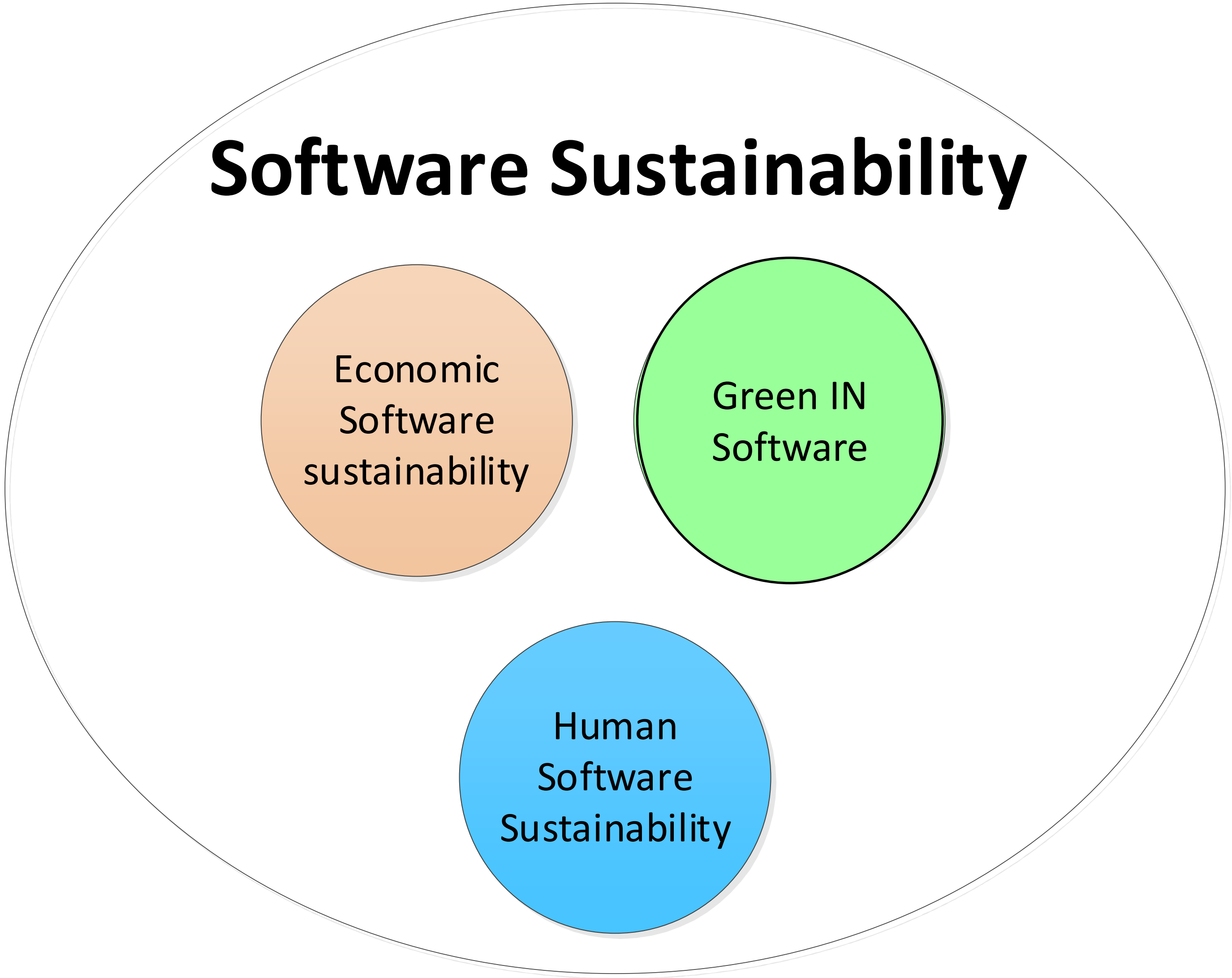
Software Sustainability

Software Sustainability

Green Software


Software Sustainability
Green Software

SOS (Software Sustainability)



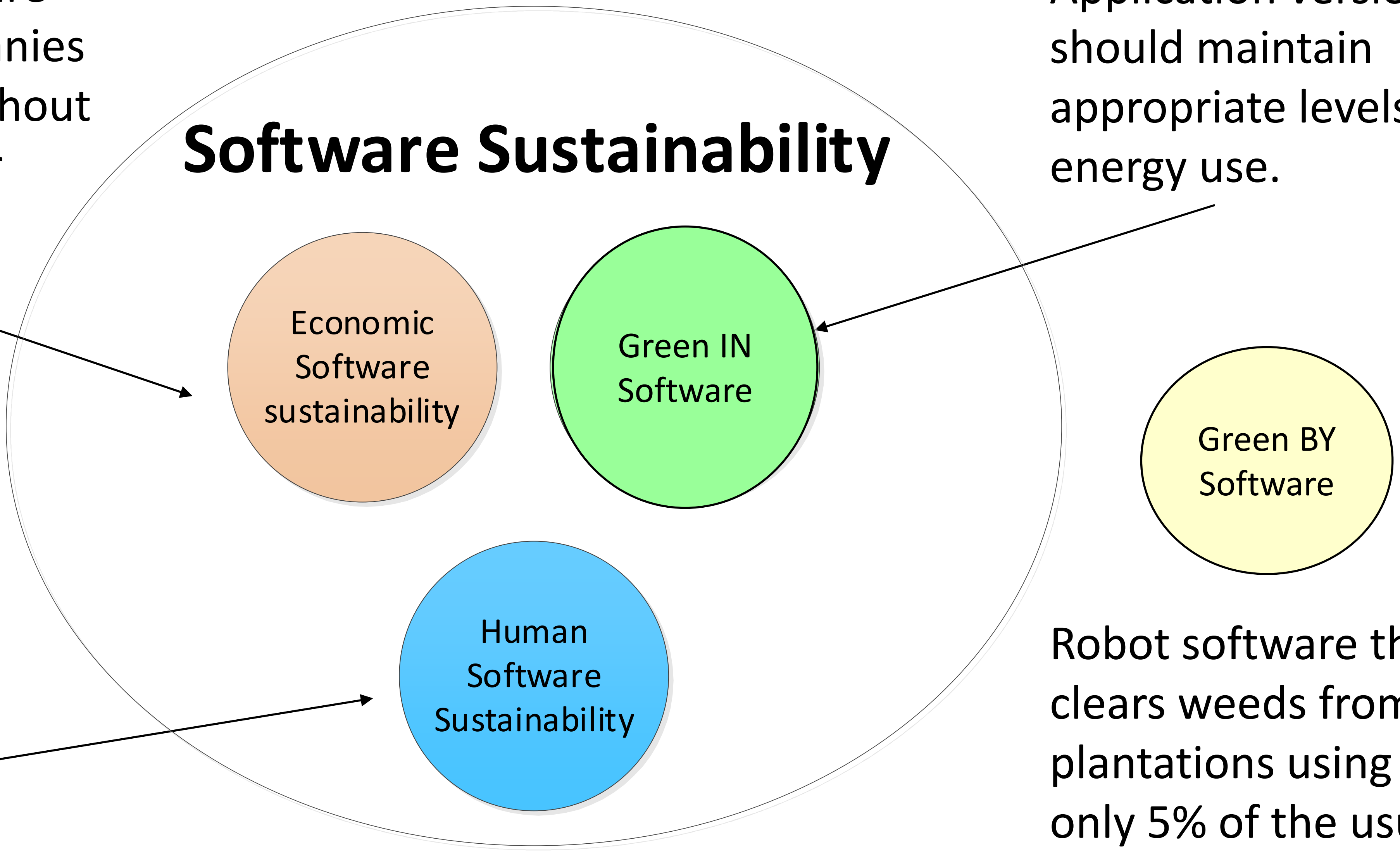
Software Sustainability

Sustainable Software is software, whose direct and indirect negative impacts on economy, society, human beings, and environment that result from development, deployment, and usage of the software are minimal and/or which have a positive effect on sustainable development.

Dick, M. and S. Naumann Enhancing Software Engineering Processes towards Susainable Software Product Design. 24th International Conference EnviroInfo. K.Greve and A.B. Cremers, Eds. Shaker, Aachen, 2010. pp. 706-715.

The profits of software development companies must be secured without this leading to unfair salaries.

Application versions should maintain appropriate levels of energy use.

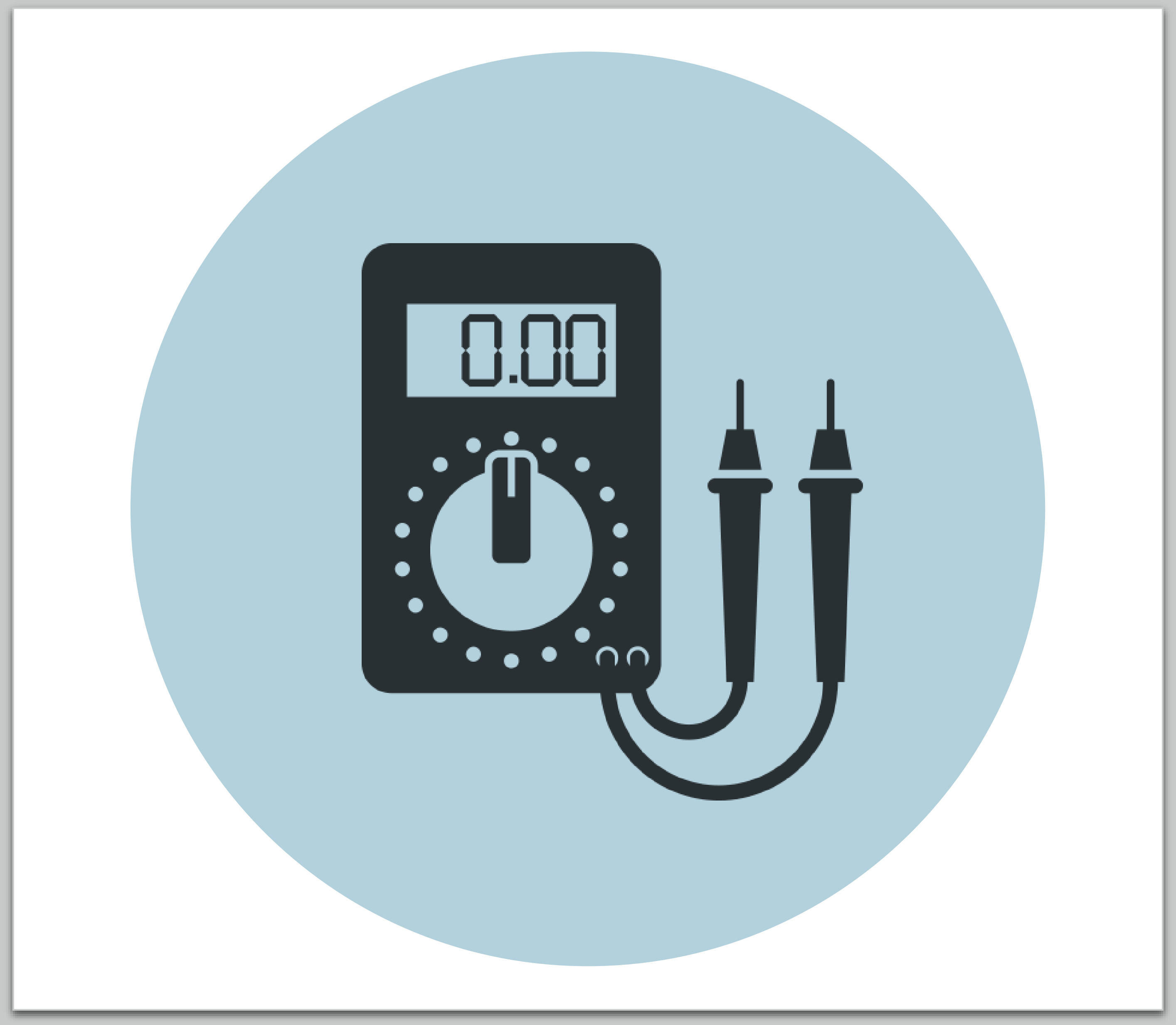


Companies provide adequate training and promotion programmes for their employees.

Robot software that clears weeds from plantations using only 5% of the usual herbicide, applying products only where needed.

Green IN Software

If we want to measure the consumption, we need an **artifact** to do it



Software-based approach

Measuring instrument	Sampling frequency	Software granularity						Hardware level of details						
		OS	Application	Process	Thread	Method	Line of code	CPU	Memory	GPU	HDD	Network	Monitor	Whole machine
Intel Power Gadget	1-1k Hz [3]	✓						✓	✓					
RAPL	1k Hz	✓						✓	✓	✓				
Powerstat	Custom [5]	✓		✓				✓	✓	✓				✓
PowerTop	1 Hz	✓	✓	✓				✓			✓	✓	✓	✓
Perf	Custom [5] (Default 1k Hz)	✓	✓	✓				✓	✓	✓				
Likwid	1 Hz	✓						✓	✓					
Nvidia-smi	1-6 Hz [6]	✓	✓	✓		✓				✓				
Intel VTune Profiler	1Hz-100kHz [2]		✓			✓		✓	✓	✓				
JouleMeter	1 Hz	✓	✓					✓	✓		✓		✓	✓
SoftWatt	Every clock cycle		✓		✓	✓		✓	✓		✓			

Measuring instrument	Sampling frequency	Software granularity						Hardware level of details						
		OS	Application	Process	Thread	Method	Line of code	CPU	Memory	GPU	HDD	Network	Monitor	Whole machine
Energy Efficiency Tester (EET)	100 Hz													
LEAP node	10 Hz													
Kill A Watt	-													
Efergy Elite	[1]													
Wemo Insight Smart Plug	1 Hz													
Sense Home Energy Monitor (Two clamp-on current sensors)	[4]													
Watts Up? Pro	1 Hz													

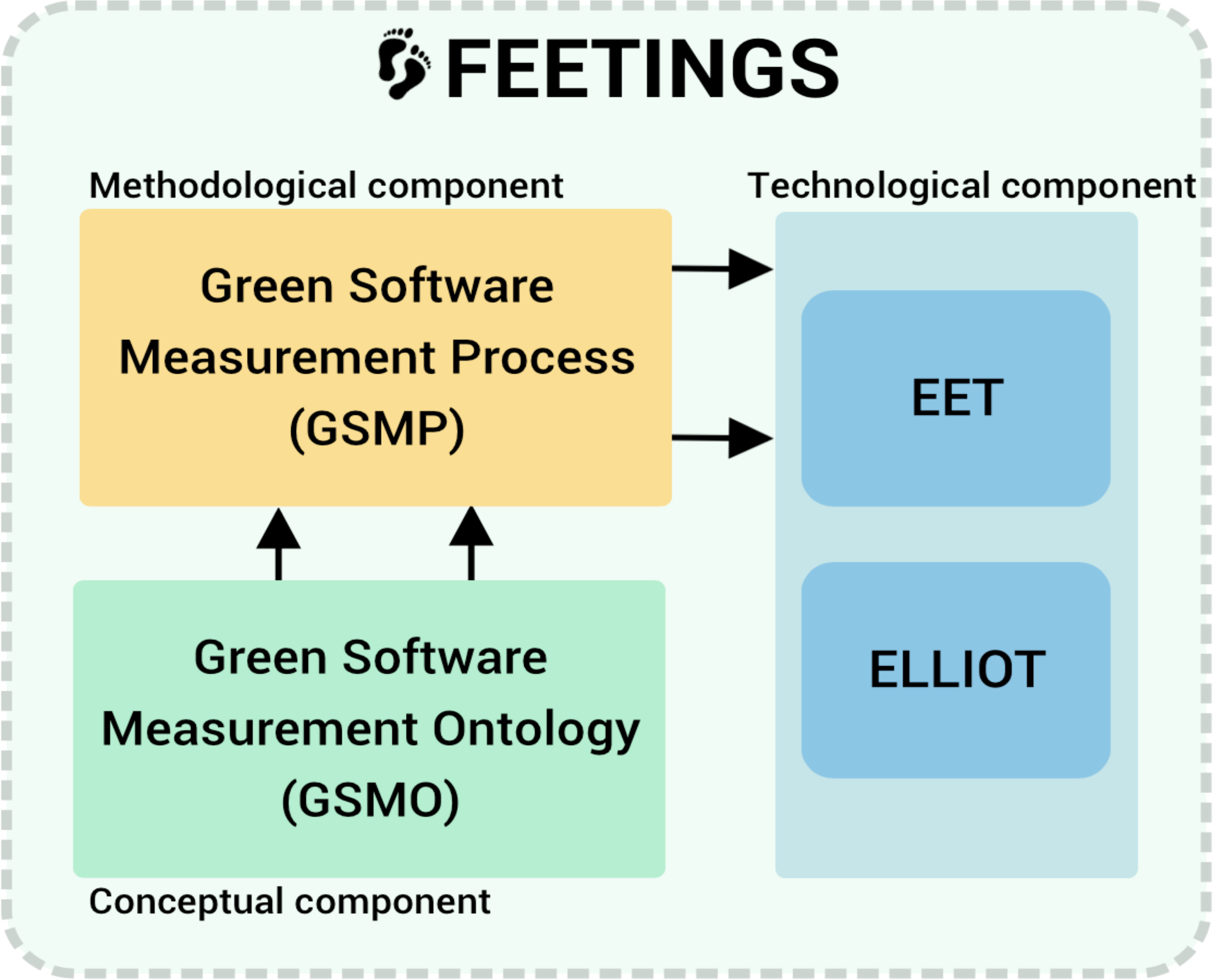
Hardware-based approach

We also need to know **how** to measure the consumption.

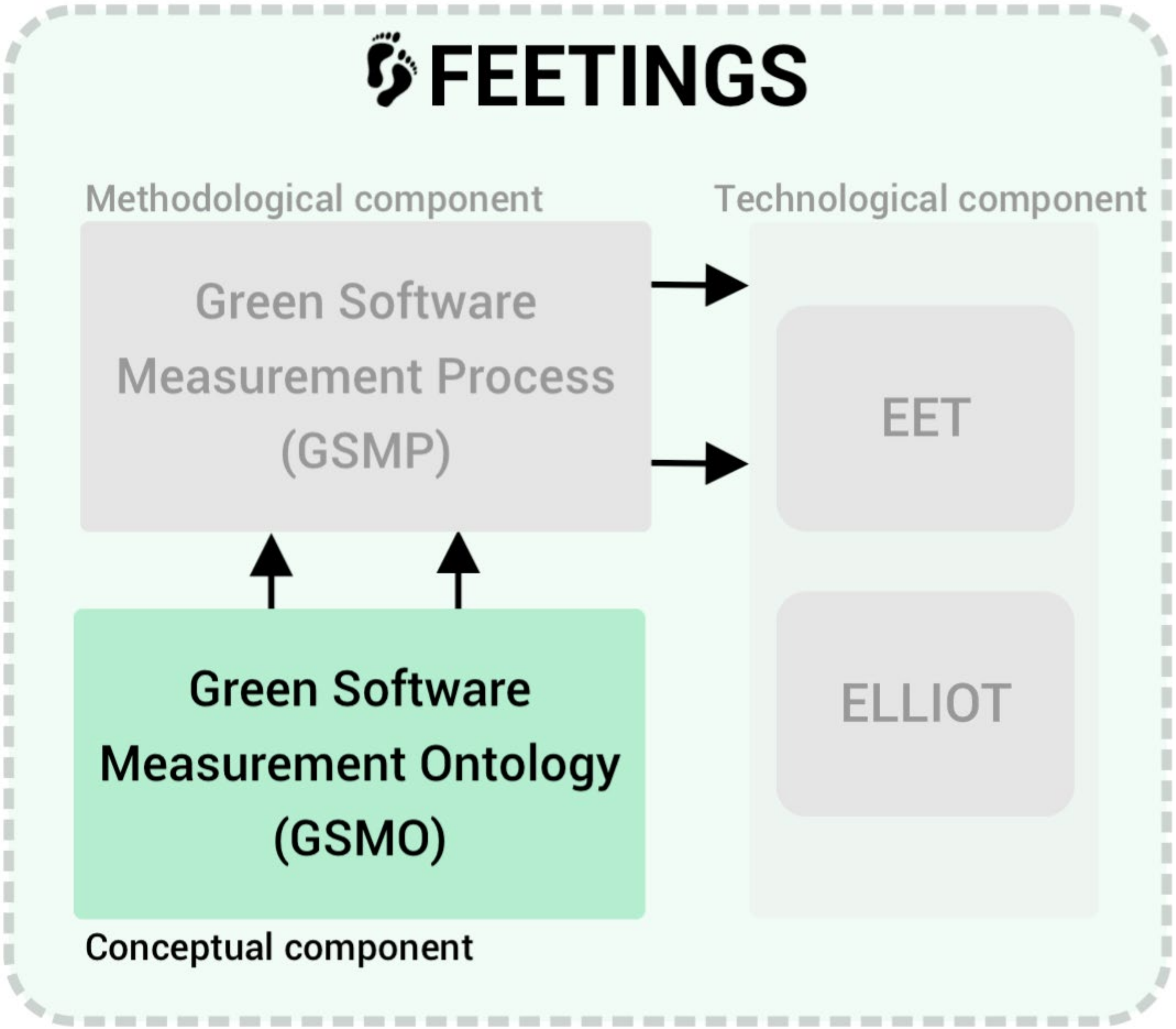
Methodologies and standards

	Software Measurement				Software Energy Measurement	
	GQM	GQ(I)M GDSM	PSM	ISO 15939	Green Mining	Jagroep et al.
Guidelines for the software measurement process	✓	✓	✓	✓	✓	✓
Specific guidelines for analyzing the data		✓	✓			
Specific guidelines for reporting results			✓	✓		
Guidelines for the process of analyzing software energy efficiency					✓	✓
Specific guidelines for carrying out energy measurements of software						✓

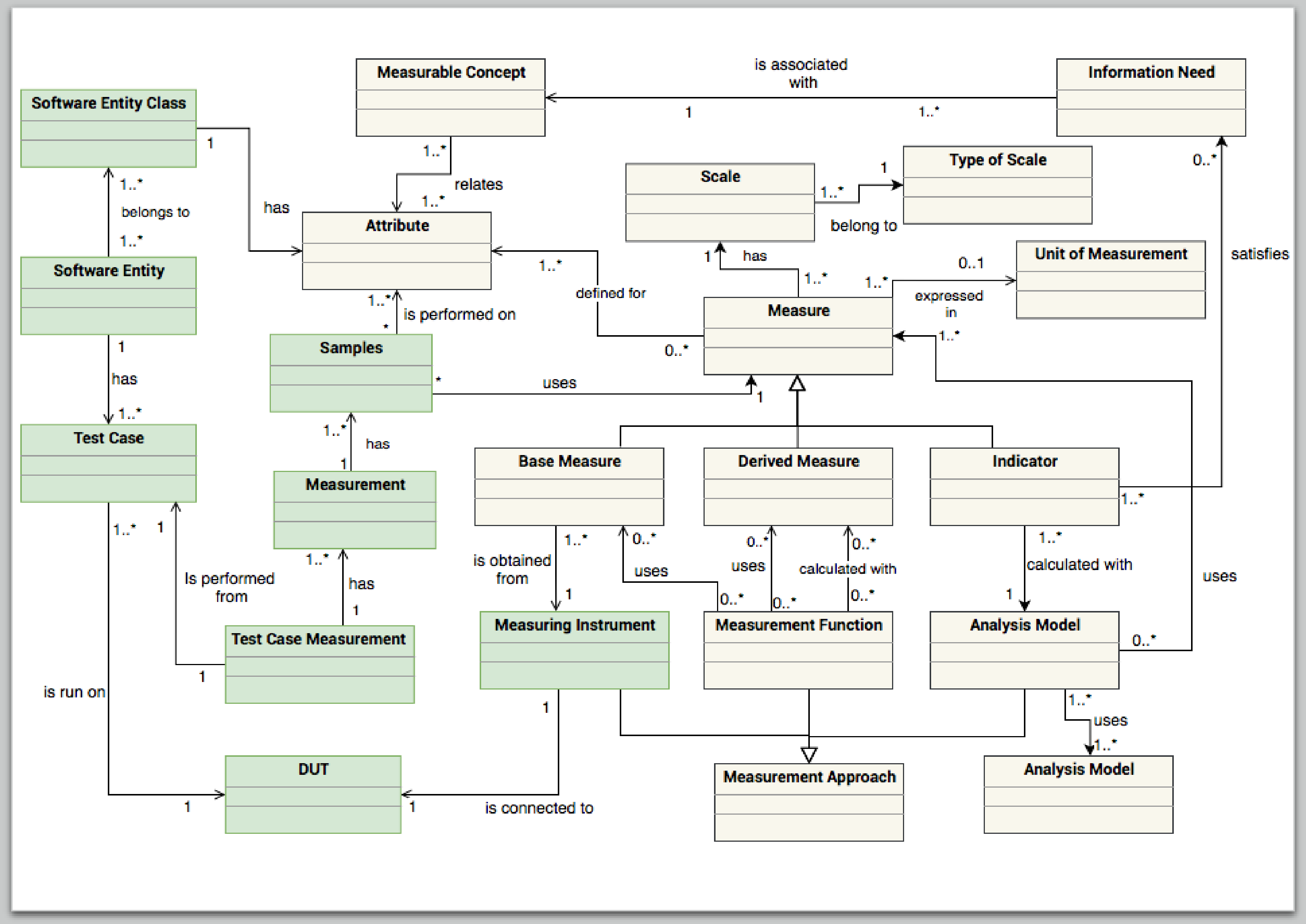
FEETINGS (Framework for Energy Efficiency Testing to Improve eNviromental Goals of the Software)

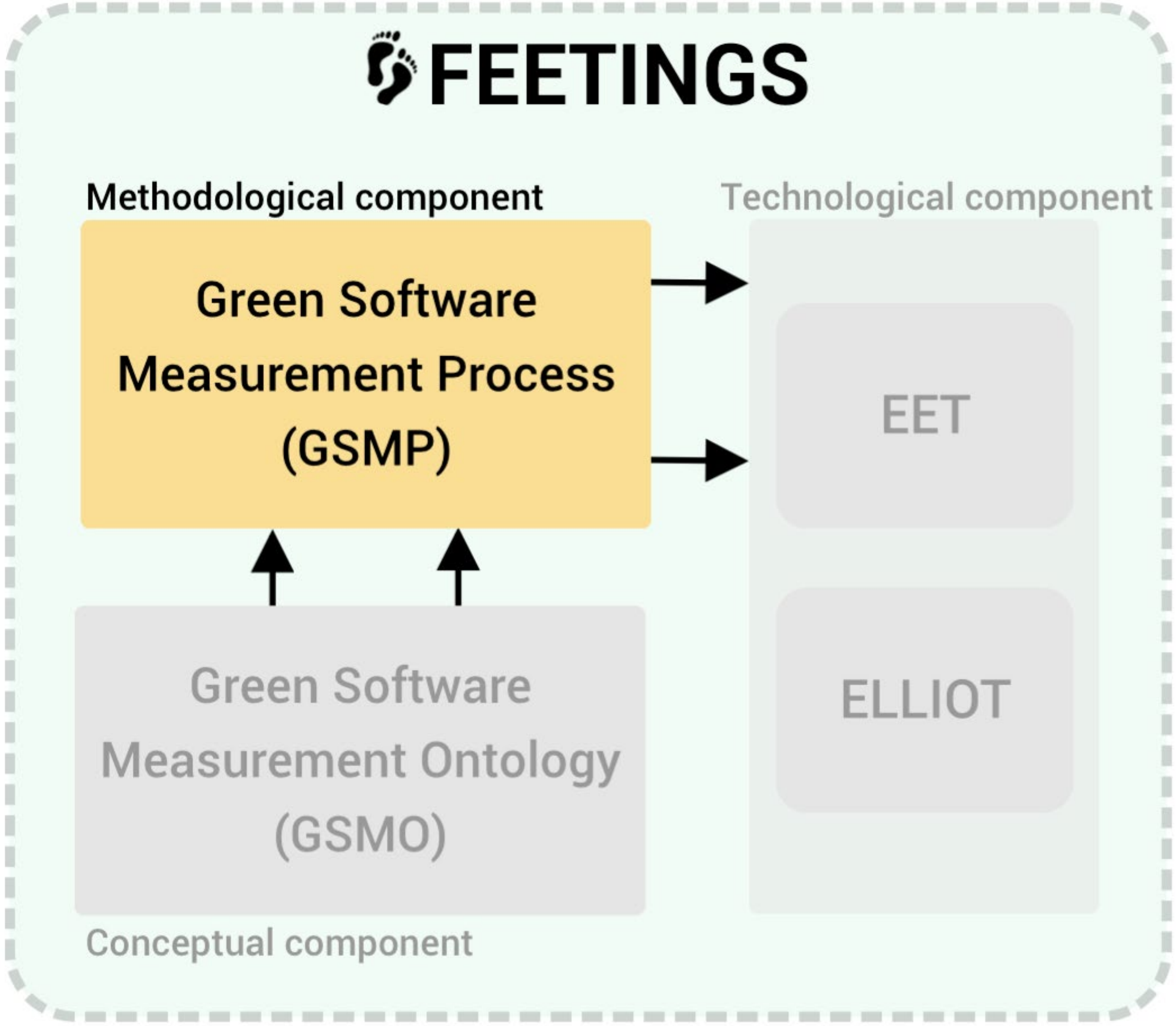


J. Mancebo, C. Calero, F. Garcia, M.A. Moraga, I. Garcia (2021). FEETINGS: Framework for Energy Efficiency Testing to Improve Environmental Goal of the Software, Sustainable Computing: Informatics and Systems, Vol. 30, 100558, https://doi.org/10.1016/j.suscom.2021.100558.


FEETINGS
Methodological component
Technological component
Green Software Measurement Process (GSMP)
EET
ELLIOT
Green Software Measurement Ontology (GSMO)
Conceptual component

Green Software Measurement Ontology (GSMO)




FEETINGS
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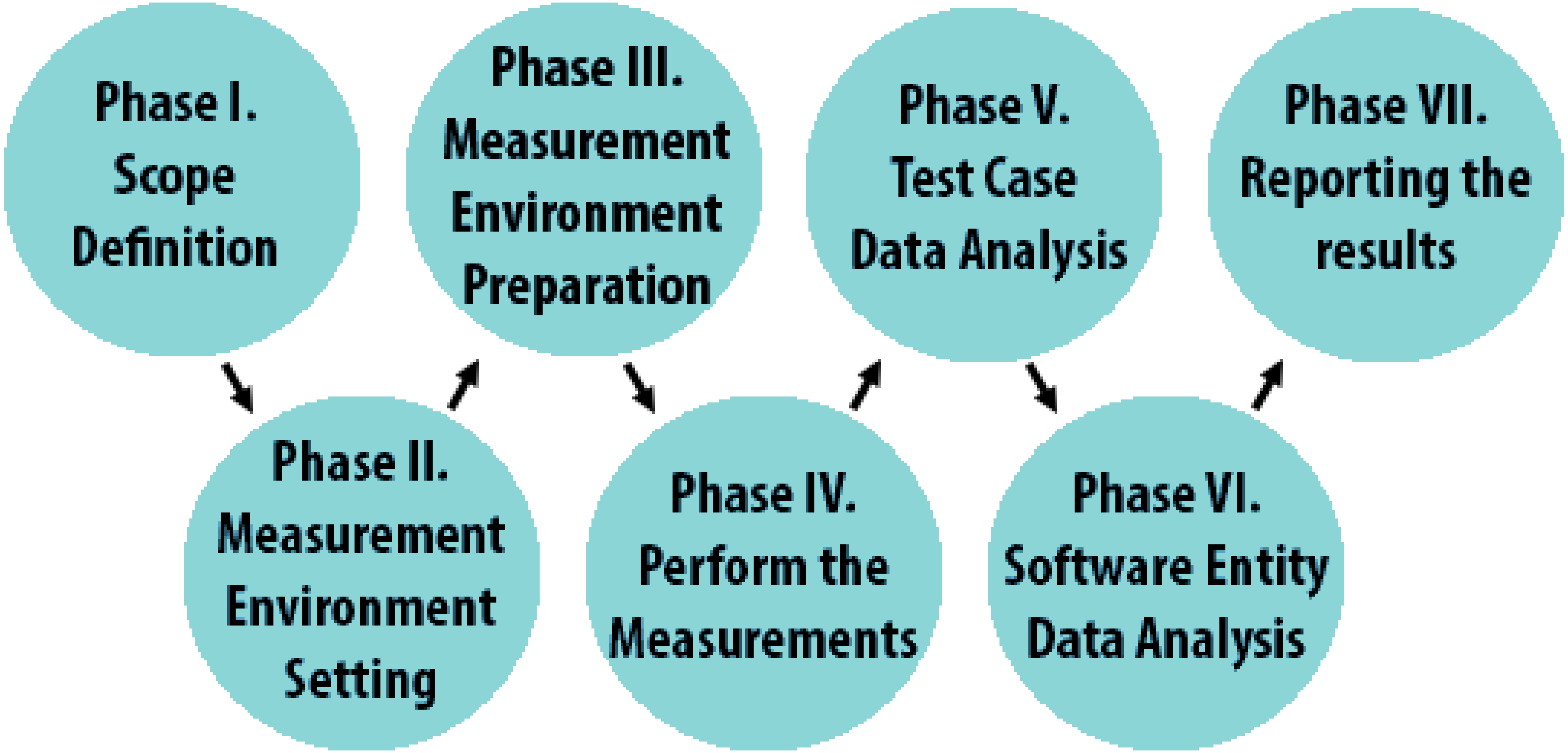
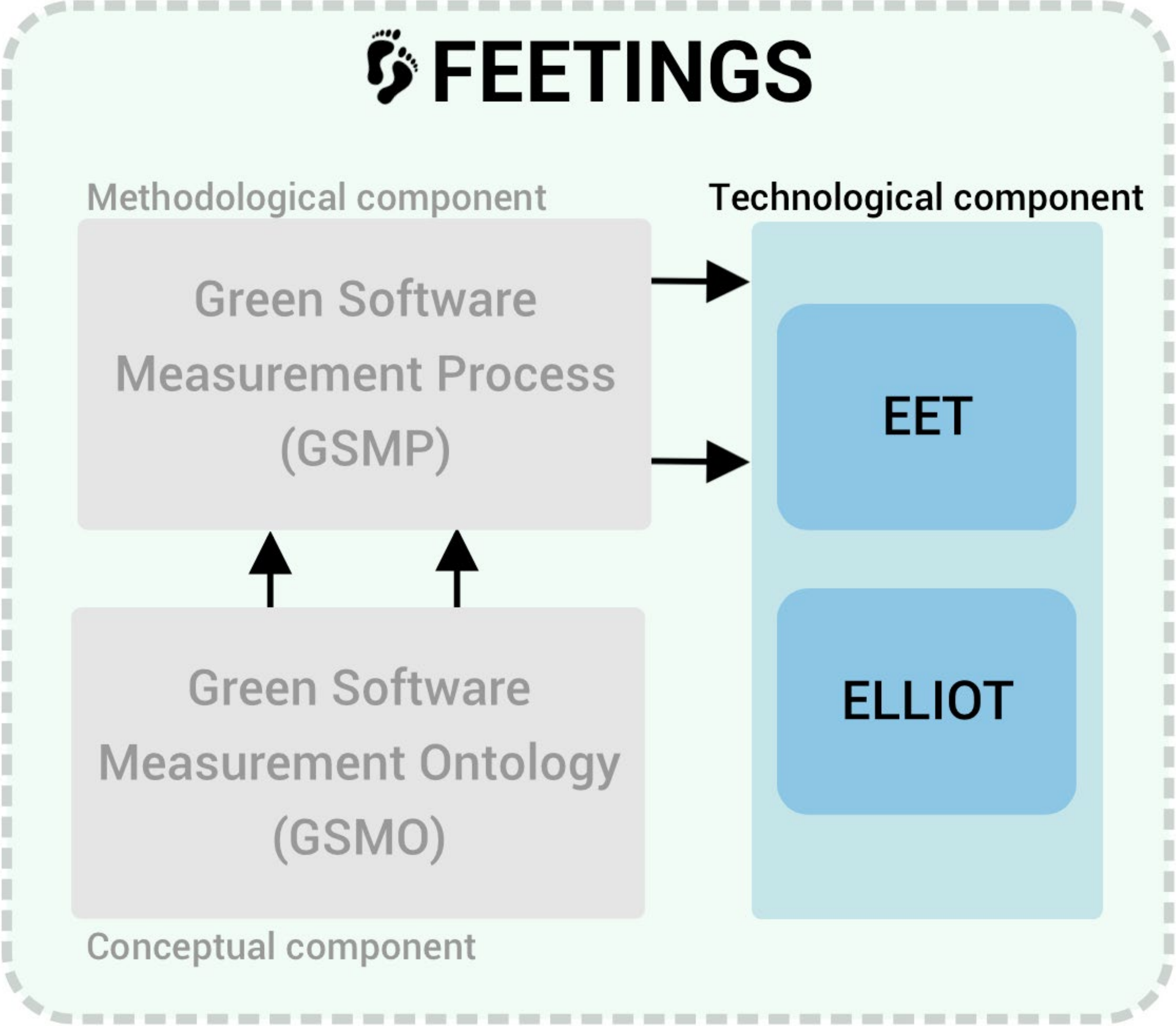
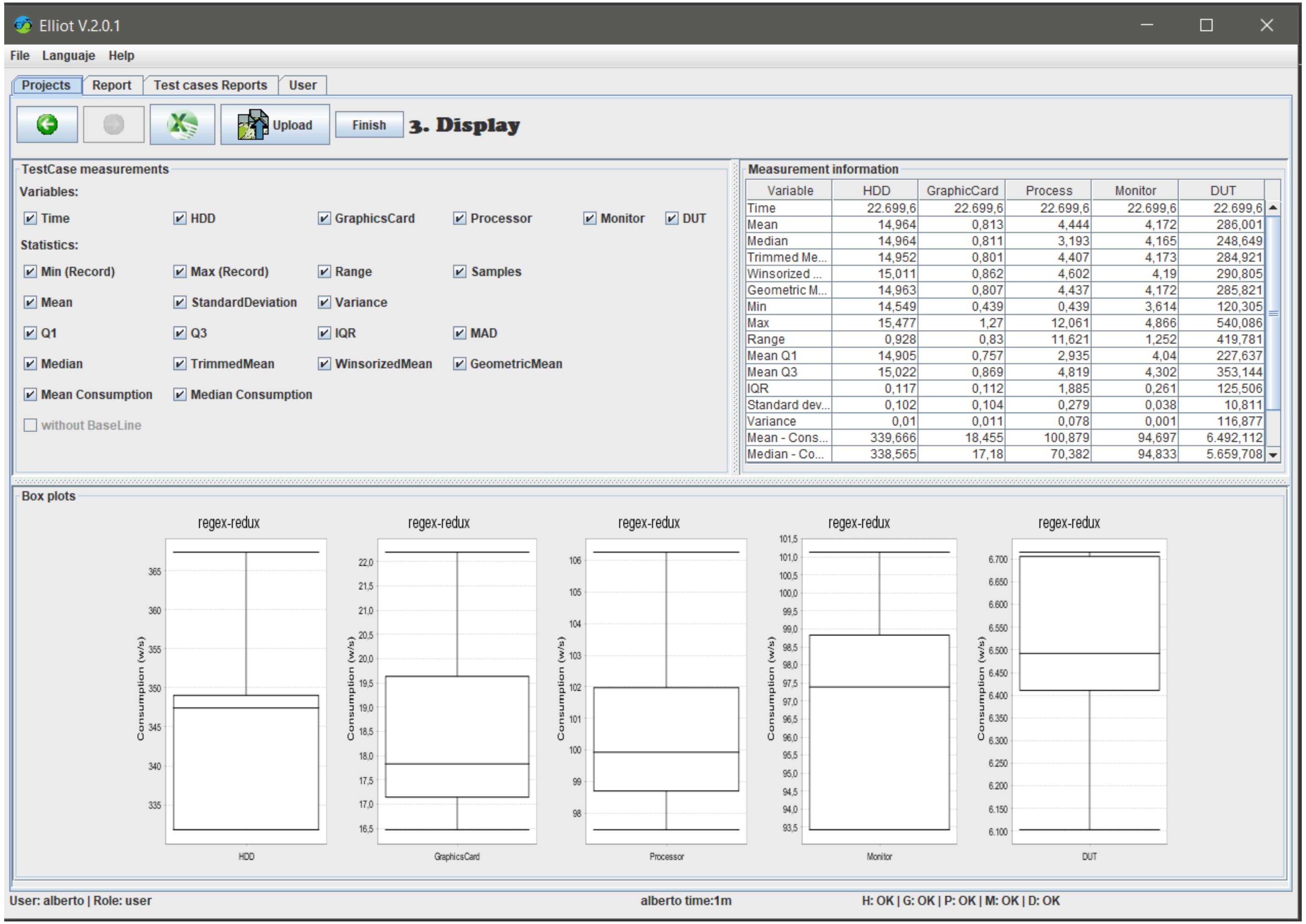


J. Mancebo, F. García, C. Calero (2021) A process for analysing the energy efficiency of software, Information and Software Technology, Vol.134,106560, https://doi.org/10.1016/j.infsof.2021.106560.


FEETINGS
Methodological component
Green Software Measurement Process (GSMP)
Technological component
EET
ELLIOT
Green Software Measurement Ontology (GSMO)
Conceptual component

EET+ELLIOT


Alarcos
Research Group
MicroSD Card Adapter
MicroSD Card Adapter


Elliot V.2.0.1
File Languaje Help
Projects Report Test cases Reports User
Upload Finish 3. Display
TestCase measurements
Variables:
Time HDD GraphicsCard Processor Monitor DUT
Statistics:
Min (Record) Max (Record) Range Samples
Mean StandardDeviation Variance
Q1 Q3 IQR MAD
Median TrimmedMean WinsorizedMean GeometricMean
Mean Consumption Median Consumption
without BaseLine
Measurement information
Variable HDD GraphicCard Process Monitor DUT
Time 22.699,6 22.699,6 22.699,6 22.699,6 22.699,6
Mean 14,964 0,813 4,444 4,172 286,001
Median 14,964 0,811 3,193 4,165 248,649
Trimmed Me... 14,952 0,801 4,407 4,173 284,921
Winsorized ... 15,011 0,862 4,602 4,19 290,805
Geometric M... 14,963 0,807 4,437 4,172 285,821
Min 14,549 0,439 0,439 3,614 120,305
Max 15,477 1,27 12,061 4,866 540,086
Range 0,928 0,83 11,621 1,252 419,781
Mean Q1 14,905 0,757 2,935 4,04 227,637
Mean Q3 15,022 0,869 4,819 4,302 353,144
IQR 0,117 0,112 1,885 0,261 125,506
Standard dev... 0,102 0,104 0,279 0,038 10,811
Variance 0,01 0,011 0,078 0,001 116,877
Mean - Cons... 339,666 18,455 100,879 94,697 6.492,112
Median - Co... 338,565 17,18 70,382 94,833 5.659,708
Box plots
regex-redux regex-redux regex-redux regex-redux regex-redux
Consumption (w/s)
HDD GraphicsCard Processor Monitor DUT
User: alberto | Role: user
alberto time:1m
H: OK | G: OK | P: OK | M: OK | D: OK

Two main types of activities

Dissemination research

Formal research

Dissemination research

Browsers+Search Engines

Social Networks

Automatic Translators

Streaming services

Results from 2021

A	Microsoft Edge + Google	Firefox + Bing	chrome + Google	Firefox + DuckDuckGo
B	Firefox + ECOSIA	brave + Google	chrome + DuckDuckGo	Microsoft Edge + DuckDuckGo
C	Microsoft Edge + ECOSIA	brave + Bing	chrome + Bing	brave + ECOSIA
D	chrome + ECOSIA	Firefox + Google	Microsoft Edge + Bing	brave + DuckDuckGo
E	Opera + Google	Opera + DuckDuckGo	Opera + ECOSIA	Opera + Bing

Formal Research

Artificial Intelligence

- Energy efficiency of AI algorithms
- Training and usage consumption of AI algorithms
- Use of compressed data or compact data structures

In collaboration with
Universidad de A Coruña (Spain)

Data compression algorithms

Mancebo, J., Calero, C., García, F., Brisaboa, N.R., Fariña, A. and Pedreira, O (2019) Saving Energy in Text Search Using Compression. GREEN 2019 : The Fourth International Conference on Green Communications, Computing and Technologies. IARIA, 2019. ISBN: 978-1-61208-751-1

Maintenance and energy consumption

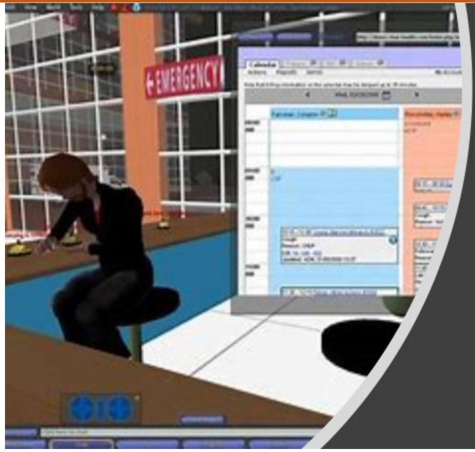
Calero, C., Polo, M. and Moraga, M.A. (2021) Investigating the impact on execution time and energy consumption of developing with Spring, Sustainable Computing: Informatics and Systems, Vol.32, 100603, December 2021, ISSN 2210-5379, https://doi.org/10.1016/j.suscom.2021.100603.

Design Patterns

Maintainability vs. Energy Efficiency

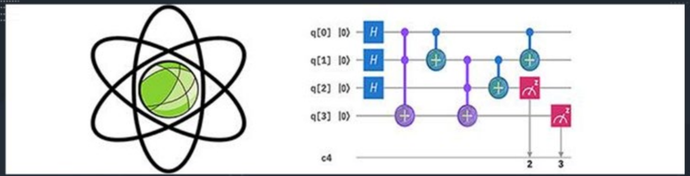
In collaboration with
Universidade do Porto (Portugal)

Programming languages consumption



Personal Health Records vs. Energy Efficiency

En colaboración con la Universidad de Murcia



Green quantum

- Comparison of quantum computers consumption
- Quantum vs. classical development

Software Sustainability

Software industries CSR and software sustainability

Dashboard for software Sustainability monitoring

Data compression algorithms

In collaboration with

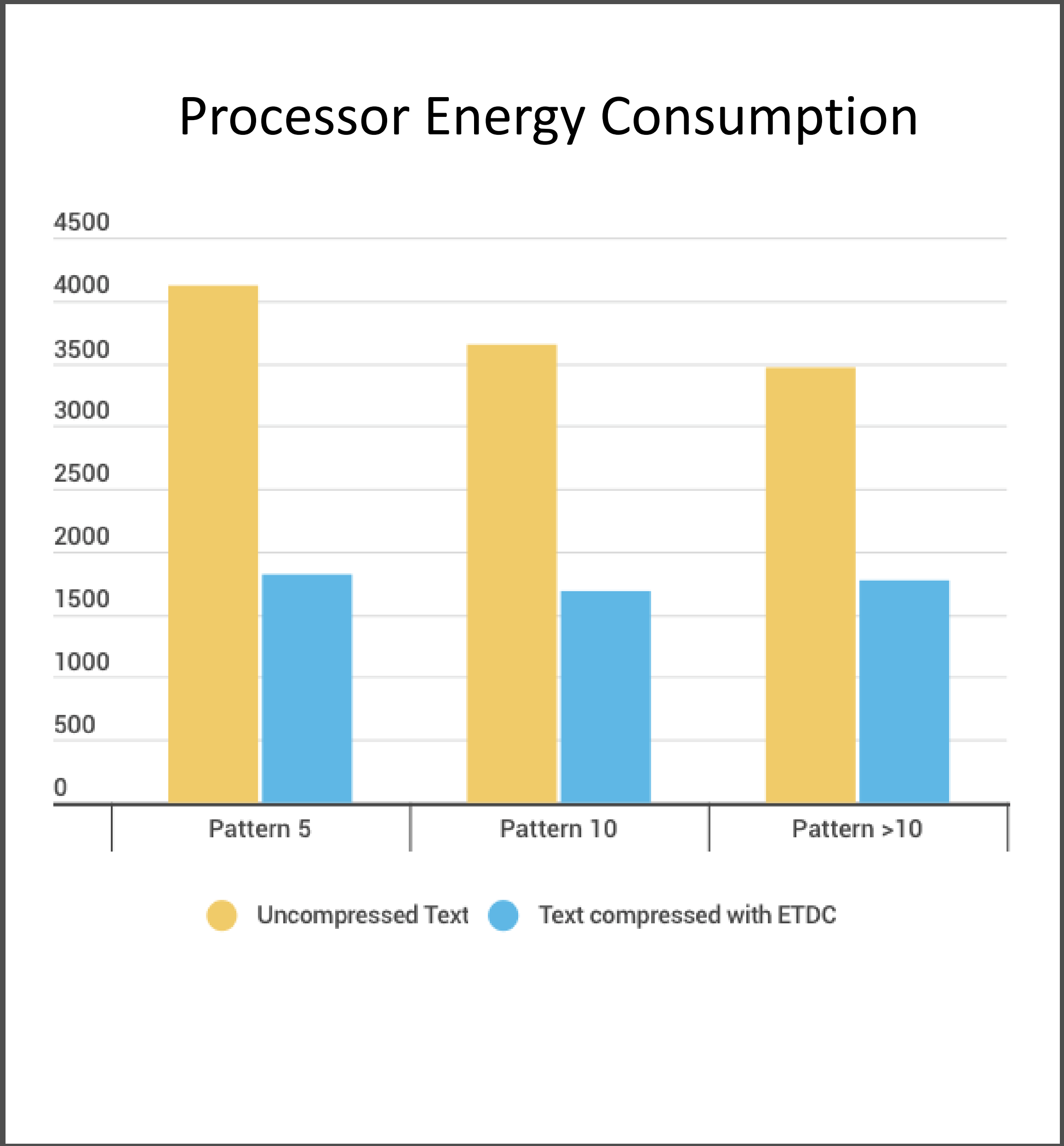
Universidad de A Coruña (Spain)

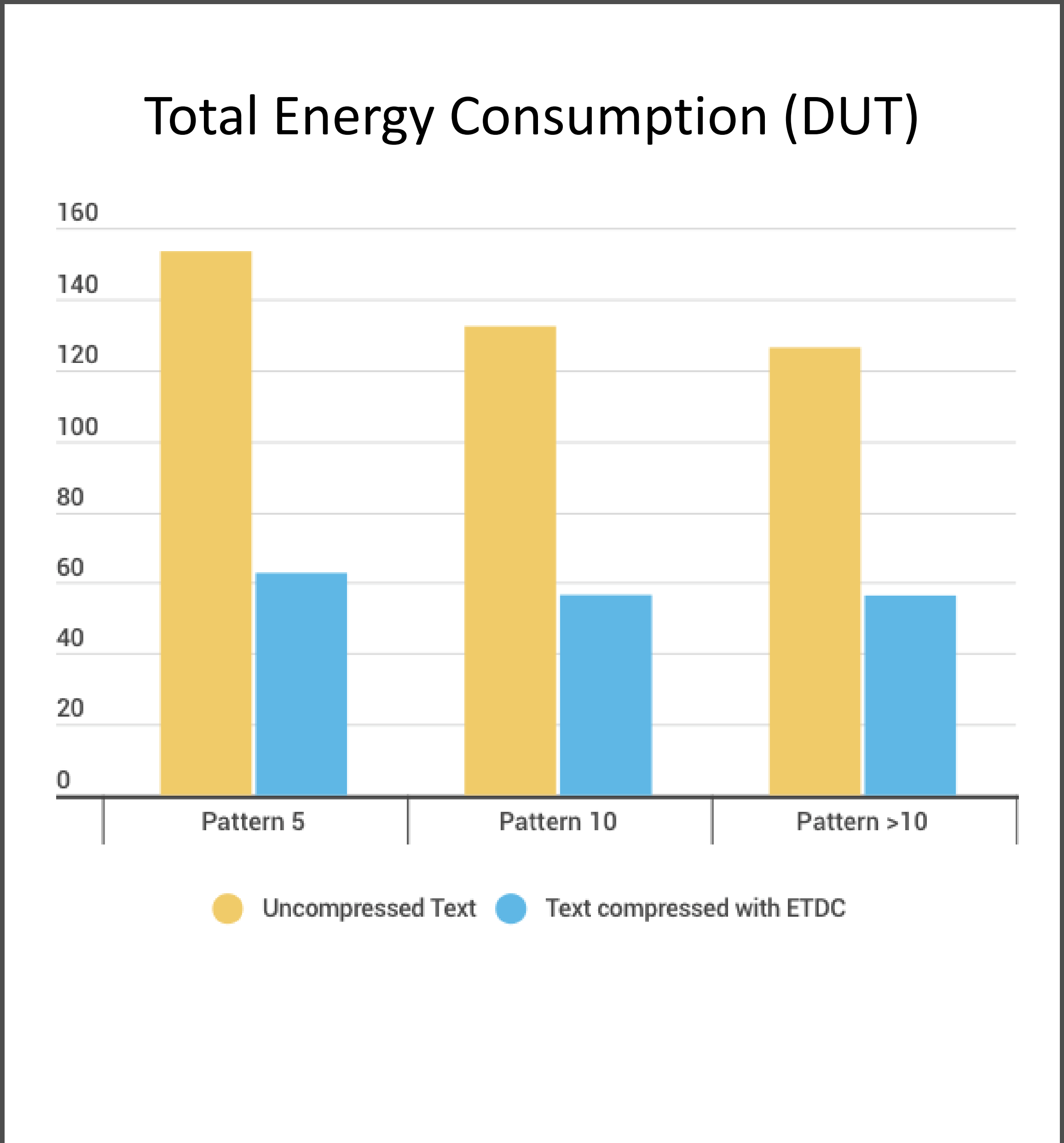
Mancebo, J., Calero, C., García, F., Brisaboa, N.R., Fariña, A. and Pedreira, O (2019) Saving Energy in Text Search Using Compression. GREEN 2019 : The Fourth International Conference on Green Communications, Computing and Technologies. IARIA, 2019. ISBN: 978-1-61208-751-1

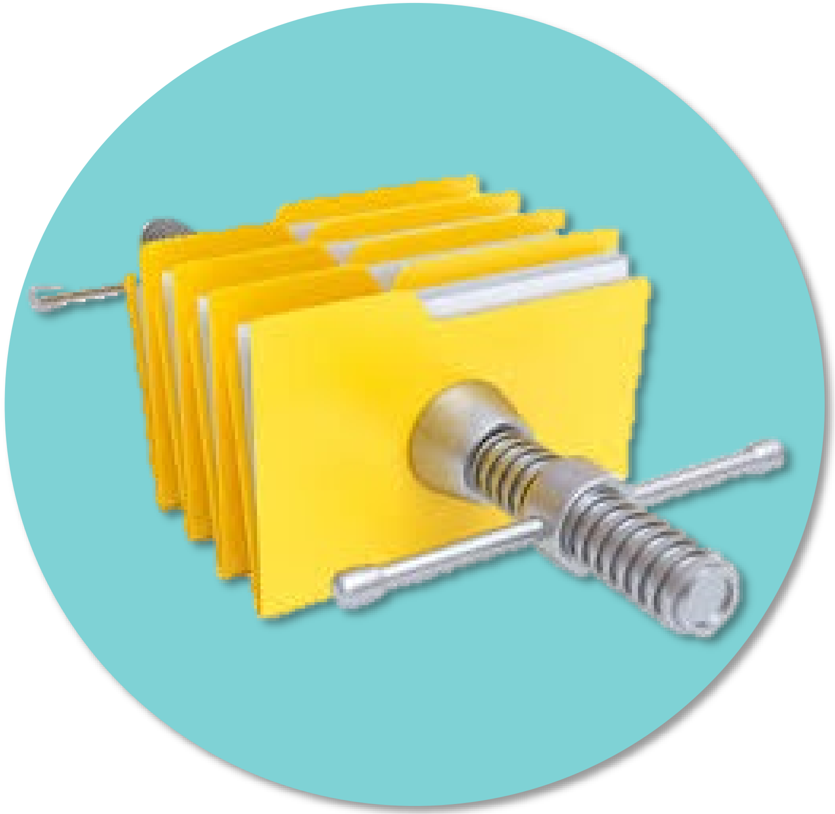
Scenarios

- Uncompressed data
- Data compressed with ETDC (End-Tagged Dense Code)

- Search of 5 characters pattern
- Search of 10 characters pattern
- Search of more than 10 characters pattern

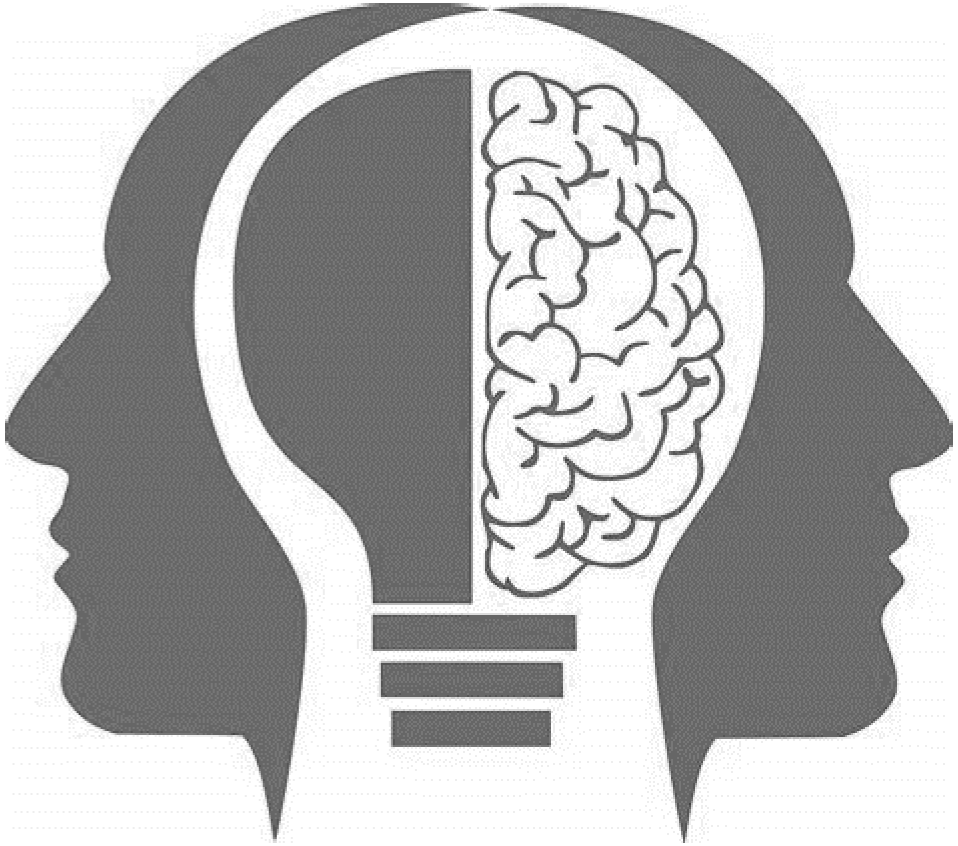

Processor Energy Consumption
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Pattern 5
Pattern 10
Pattern >10
Uncompressed Text
Text compressed with ETDC


Total Energy Consumption (DUT)
160
140
120
100
80
60
40
20
0
Pattern 5
Pattern 10
Pattern >10
Uncompressed Text
Text compressed with ETDC



Size - 30%

Energy Efficiency +50%



Artificial Intelligence

M. Gutiérrez, M. Á. Moraga, F. García and C. Calero, Green-IN Machine Learning at a Glance, *Computer*, vol. 56, no. 6, pp. 35-43, June 2023, doi: 10.1109/MC.2023.3254646.

Scenarios

ML model based on logistic regression (LRM)

&

Three solvers:

- SAG (Stochastic Average Gradient descent)
- Newton-cg (Conjugate Gradient ascent)
- LBFGS (limited-memory BFGS)

dataset for the detection of fraudulent credit card transactions

Solver	Time	Precision	Accuracy	Consumption
LBFGS	6,190.41	99.91%	0.85	1,942.52
Newton-CG	212,607.45	99.93%	0.94	58,493.58
SAG	27,133.04	99.87%	0.87	3,790.75

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LBFGS

Newton-CG

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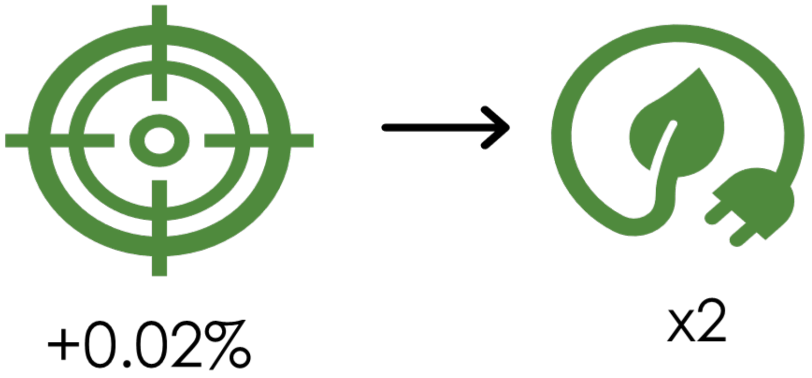

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@CoralCalero
@GreenTAlarcos
@GrupoAlarcos
@GreenTICTips

Software is becoming increasingly important

But it is a major energy consumer

It is our responsibility to make it more efficient

We are on the way (research, industry, governments)

@GreenTICTips

Periodically check spam, trash, etc. and delete permanently the emails on them.

Send emails with delivery and reading confirmation only if necessary.

It is better to share a document in a repository than send it to many people.

Clear your browser history periodically

Schedule automatic shutdown of devices after a certain period of inactivity.

Delete digital content that you do not use (i.e. repeated or discarded photos) and review and delete images or content received through social networks

In social networks, avoid using audio or video. Instead use text or emojis.

Avoid forwarding content indiscriminately (e.g. content received via whatsapp and forwarded to many contacts).