GREEN SOFTWARE ENGINEERING

By

Gitanjali Venkatraman

INTRODUCTION

YOU ARE READING THIS BECAUSE YOU ARE a) CURIOUS AND b) CARE ABOUT THE ROLE SOFTWARE + THE IT INDUSTRY PLAY IN THE CLIMATE CRISIS.

WHILE IT IS PART OF THE PROBLEM, THE IT INDUSTRY HAS A POSITIVE PART IN SOLVING IT AS WELL.

BUILDING SOFTWARE IS DEEPLY CONNECTED TO HARDWARE, ENERGY SOURCES AND HOW THEY ARE USED.

GREEN SOFTWARE IS SOFTWARE THAT WANTS TO EMIT LESS. GREEN SOFTWARE ALSO WANTS TO HELP US EMIT LESS.

THIS ASPIRATION CAN BE REALISED THROUGH FINDING EFFICIENCIES, MEASURING PROGRESS AND COMMITTING TO TARGETS.

WHAT ARE THE ASSOCIATED TERMS IN THE INDUSTRY? WHO ARE THE BODIES THAT SET THE DIRECTION? ARE THERE ANY UNETHICAL PRACTICES TO BE AWARE OF?

STEP INTO THIS ILLUSTRATED GUIDE ON GREEN SOFTWARE ENGINEERING TO FIND THE ANSWERS AND SOME QUESTIONS.

SCOPE

CONTEXT

- UN & CLIMATE CRISIS
- TERMS
- DIGITAL EMISSIONS

PRINCIPLES

- FROM 2019
- FROM 2022

CARBON EFFICIENCY

ENERGY EFFICIENCY

- PUE
- STATIC POWER DRAW
- ENERGY PROPORTIONALITY

CARBON AWARENESS

- DEMAND SHIFTING
- DEMAND SHAPING

HARDWARE EFFICIENCY

EFFICIENCY & JEVON'S PARADOX

MEASUREMENT

- GHG PROTOCOL
- SCOPE 1 2 3
- SCI

CLIMATE COMMITMENTS

- OFFSETS
- ELIMINATION
- CARBON MARKETS
- CARBON REDUCTION
- ESG, SBTi, TNFD

GREENING OF IT

- DESIGN & CODING
- CHOICE OF LANGUAGE
- AI MODELS
- DATA CENTRES
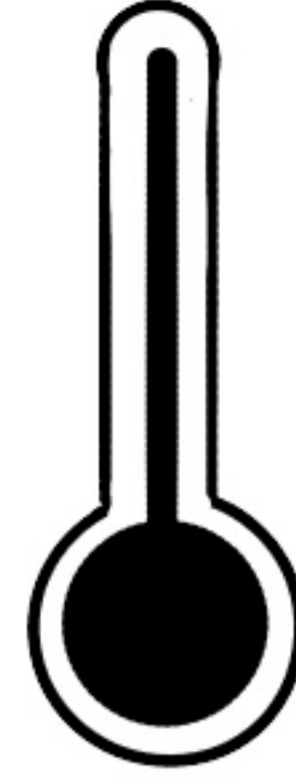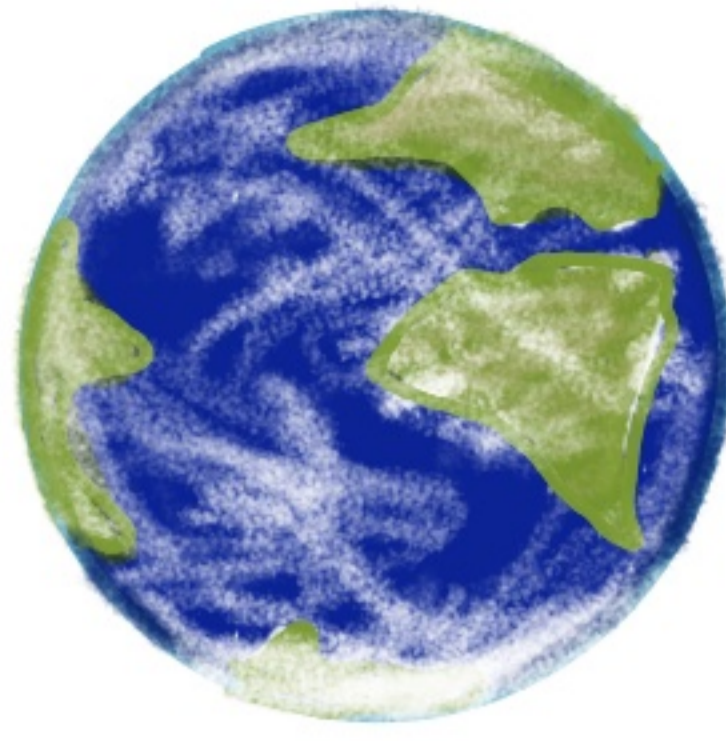
GREENING BY IT

- TOOLS & FUNCTIONS

GREENWASHING

CLIMATE RESILIENT DEVELOPMENT

QUESTIONS TO PONDER

REFERENCES

CONTEXT & TERMINOLOGY

THE UN ON CLIMATE CHANGE

CLIMATE CHANGE IS THE DEFINING ISSUE OF OUR TIME AND WE ARE AT A DEFINING MOMENT

- -

THE CONCENTRATION OF GREENHOUSE GASES - GHGs - IN THE ATMOSPHERE IS DIRECTLY LINKED TO THE AVERAGE GLOBAL TEMPERATURE ON EARTH

- -

IF GLOBAL WARMING TRANSIENTLY EXCEEDS 1.5°C IN THE COMING DECADES OR LATER, THEN MANY HUMAN AND NATURAL SYSTEMS WILL FACE ADDITIONAL SEVERE RISKS, COMPARED TO REMAINING BELOW 1.5°C

un.org/global-issues/climate-change

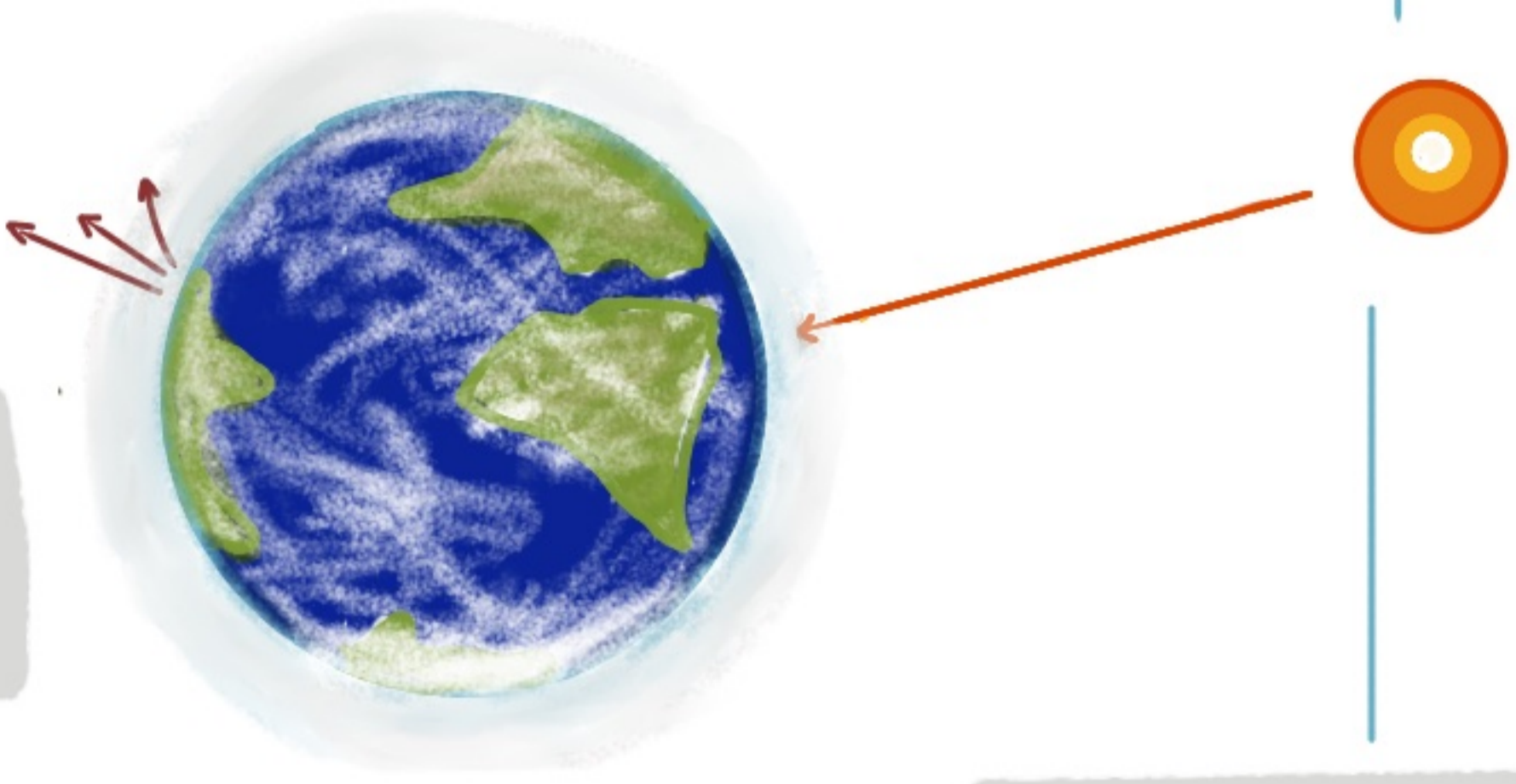TO LIMIT GLOBAL WARMING, HUMAN-CAUSED EMISSIONS OF CARBON DIOXIDE NEED TO

● FALL TO NEARLY HALF BY 2030

● REACH NET-ZERO BY 2050

GREENHOUSE GASES

SOME GASES IN THE ATMOSPHERE

GREENHOUSE GASES - GHGS
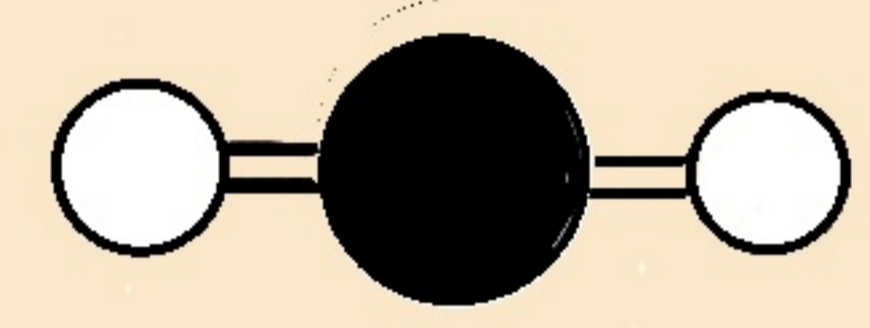
ABSORB INFRARED

TRAP HEAT

MAINTAIN EARTH TEMPERATURE

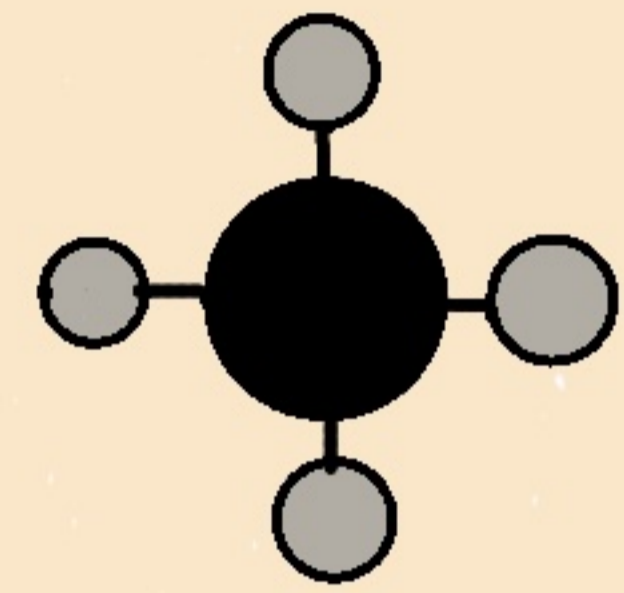-GREENHOUSE EFFECT-
— SUSTAINS LIFE —

HOWEVER...

GHG LEVELS INCREASE FROM

- HUMAN ACTIONS
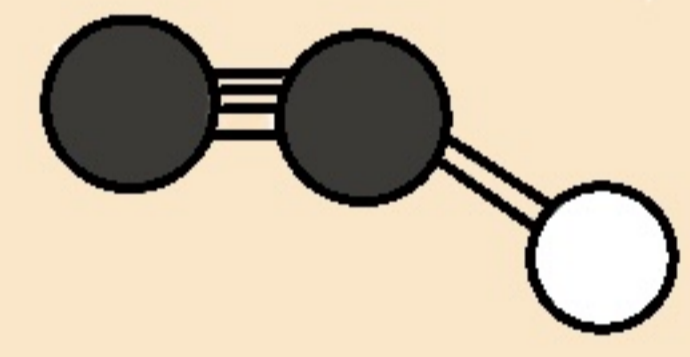- LIKE ...
- BURNING FOSSIL FUELS
- MANUFACTURING

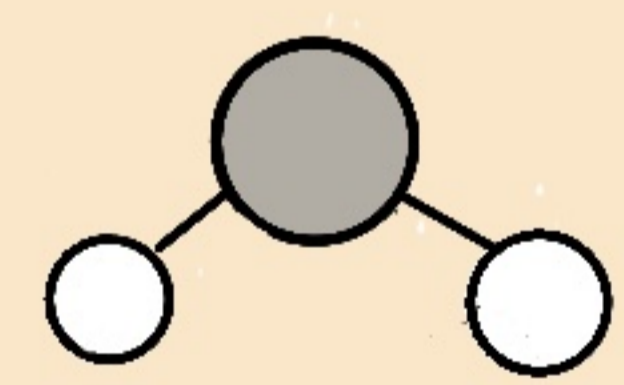THIS UPSETS THE DELICATE BALANCE AND INCREASES GLOBAL TEMPERATURES

CARBON DIOXIDE
CO_2

METHANE
CH_4

NITROUS OXIDE
N_2O

WATER VAPOUR
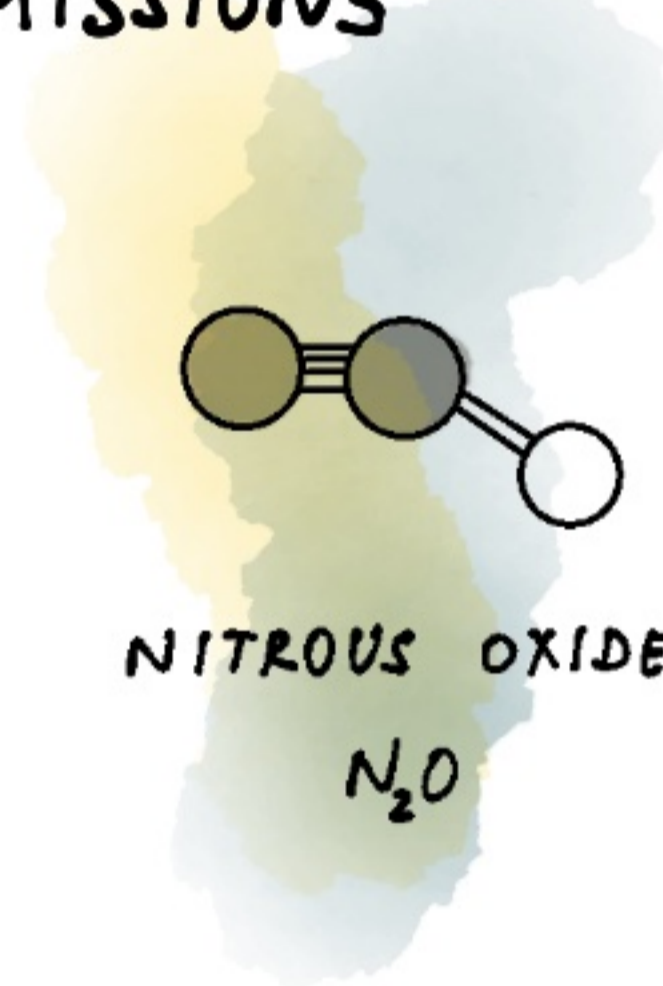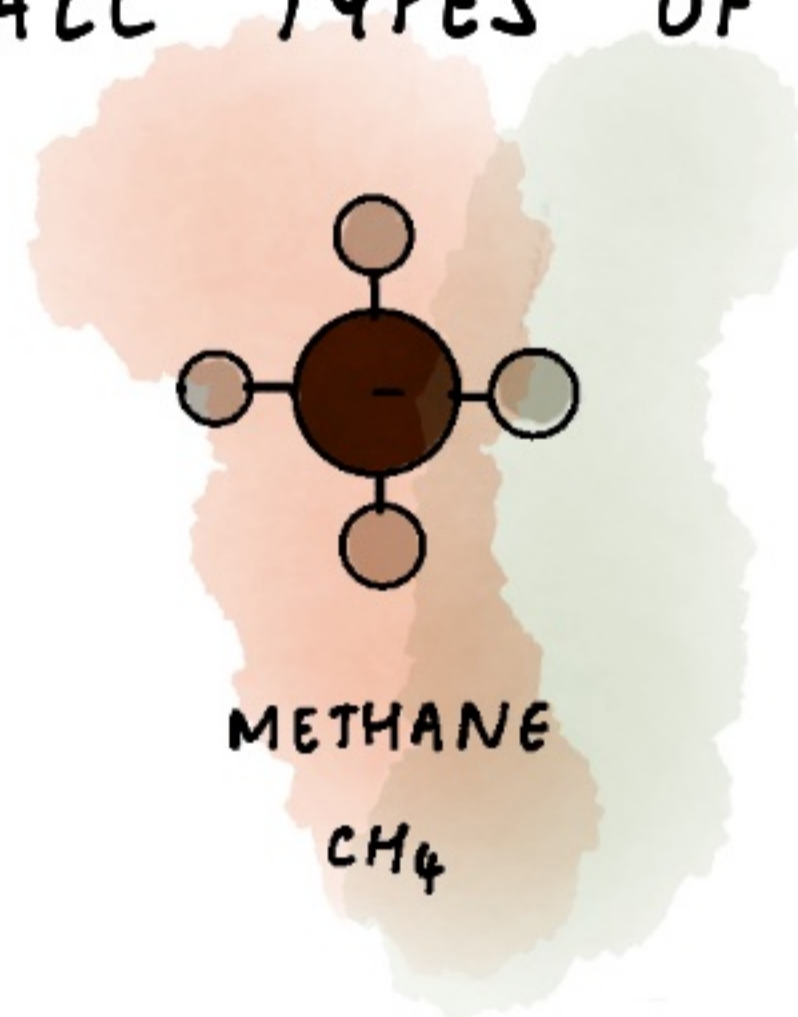H_2O

CHLORO FLUORO CARBONS

etc

CARBON

CARBON DIOXIDE CO_2

THE TERM CARBON

IS USED

TO MEAN

ALL TYPES OF EMISSIONS

CARBON DIOXIDE CO_2

METHANE CH_4

NITROUS OXIDE N_2O

CHLOROFLUORO CARBONS

etc
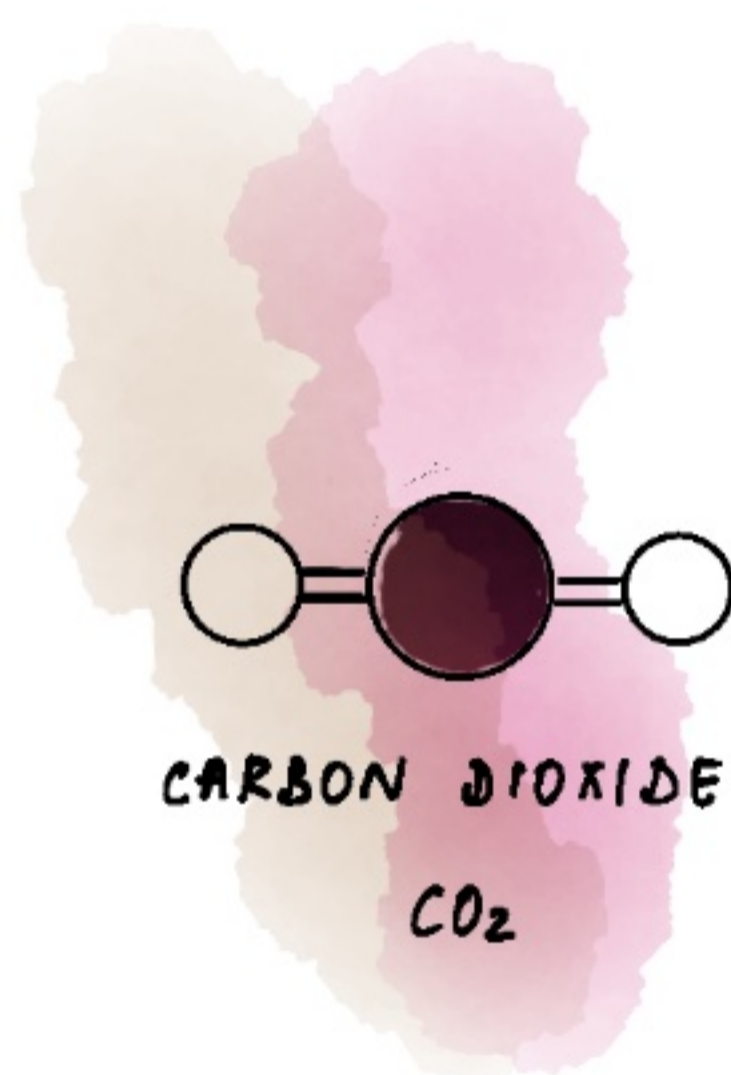
IN THE CONTEXT OF GLOBAL WARMING

A CONVERSION FACTOR IS APPLIED TO COME UP WITH CO_2E - THE CO_2 EQUIVALENT EMISSIONS OF SAY A TON OF METHANE OR OTHER GHGS

CARBON FOOTPRINT

IT IS A MEASURE OF GHG EMISSIONS FROM HUMAN ACTIVITY

UNIT OF MEASURE – METRIC TONS OF CO_2E

HOW TO MEASURE CARBON FOOTPRINT

LIST EACH TYPE OF ACTIVITY

GET EMISSION FIGURES FOR EACH ACTIVITY

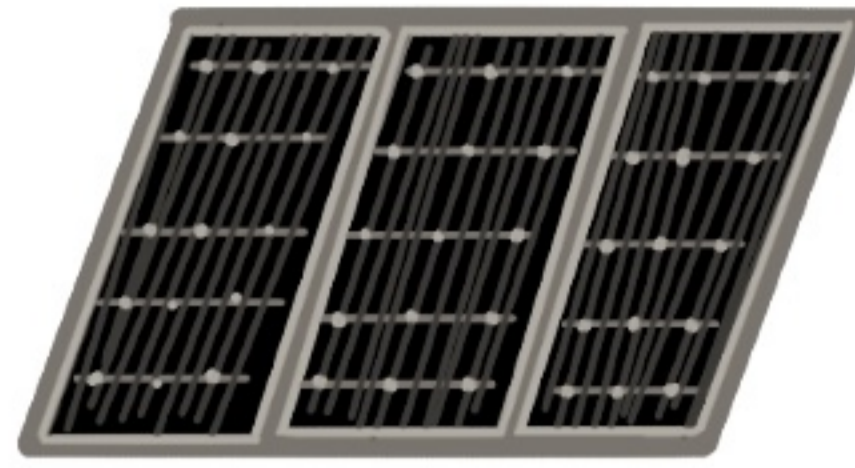| ACTIVITY	SCOPE 1	SCOPE 2	SCOPE 3
	4	13	7·0
	11	3	3·2
	33	16·00	4·12
	24	0	7·80
	36	27·—	15·00
	73	63·—	63·12
	143	24·5	8·21
TOTAL			14·8 MT CO2E

ADD UP NUMBERS FROM EACH ACTIVITY
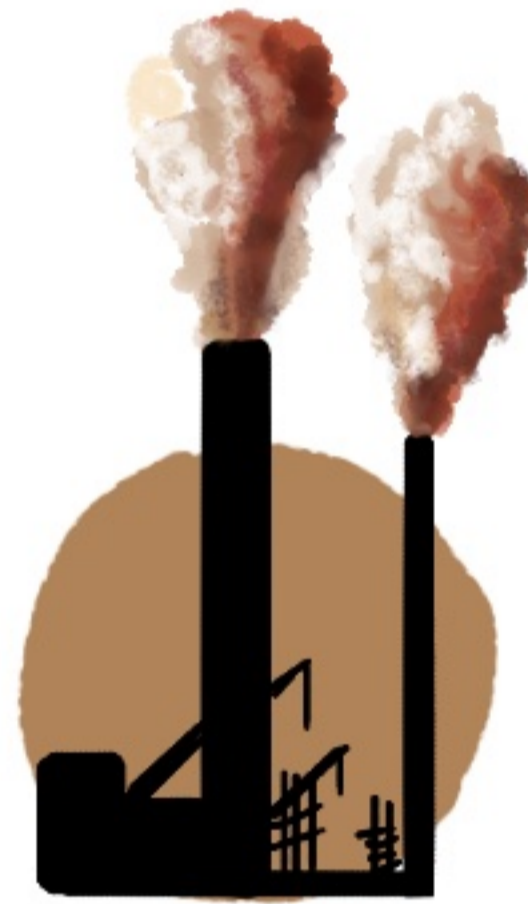
ZERO CARBON OR NET ZERO?

ZERO CARBON

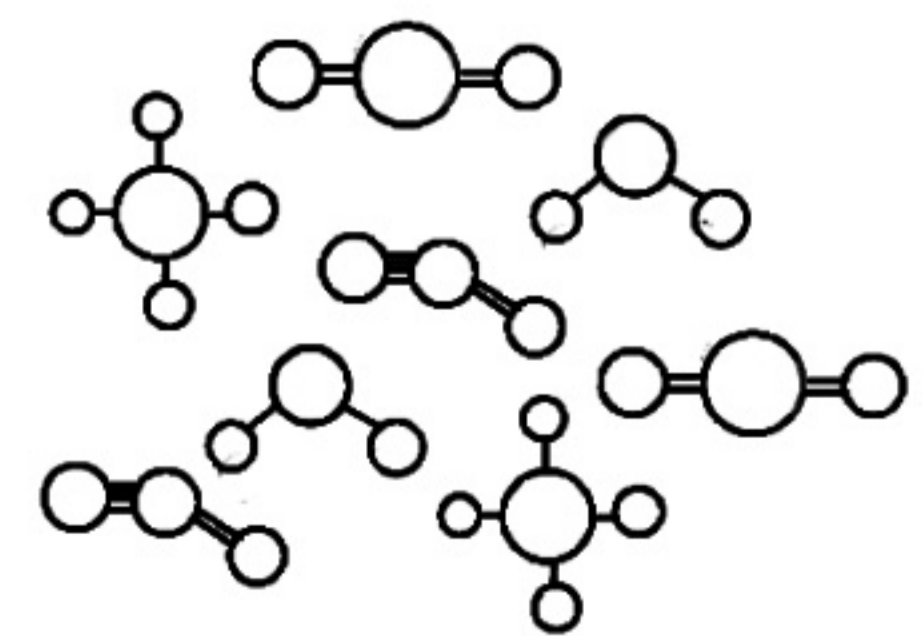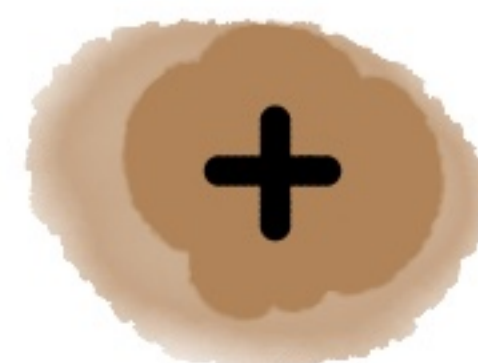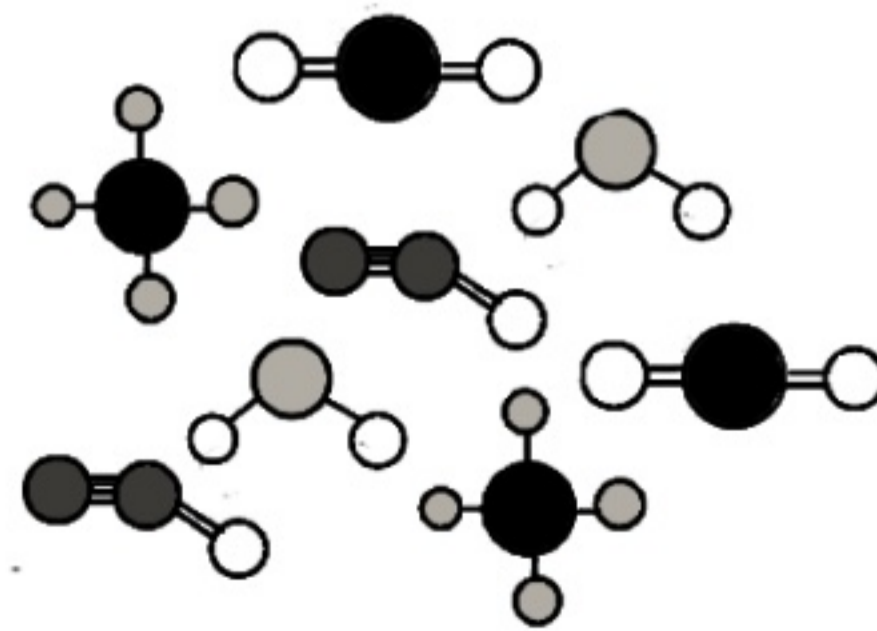MEANS THAT AN ACTIVITY DOES NOT PRODUCE ANY CARBON EMISSIONS

CARBON NEUTRALITY

IS THE BALANCE OF CARBON EMISSIONS TO REMOVING AN EQUIVALENT AMOUNT BY INVESTING IN FORESTS, OCEANS ETC.
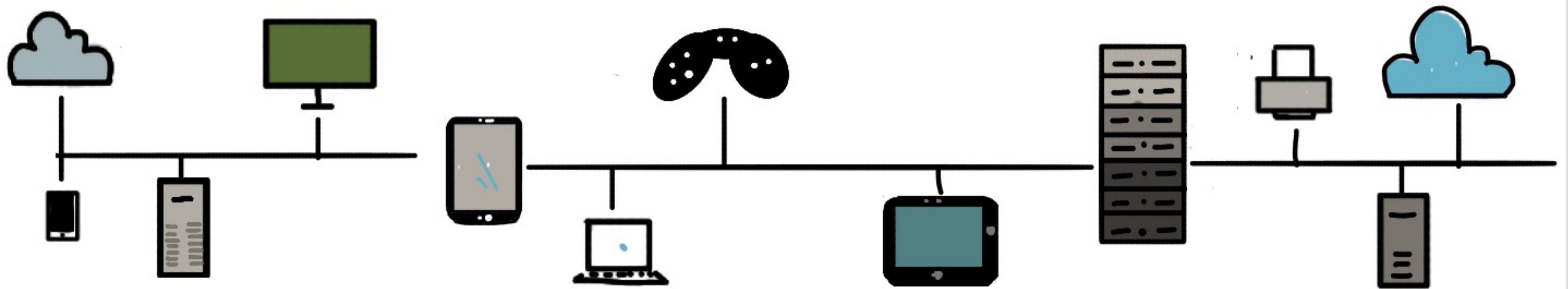
NET ZERO - A TERM WITH AMBIGUOUS PLEDGES

MEANS THERE IS A BALANCE BETWEEN ALL GHG RELEASED TO THE GHG REMOVED FROM THE ATMOSPHERE.

DIGITAL TECH & EMISSIONS

THE DATA AVAILABLE ON DIGITAL TECHNOLOGY EMISSIONS POINTS TO NEARLY **10%** CONTRIBUTION TO GHG

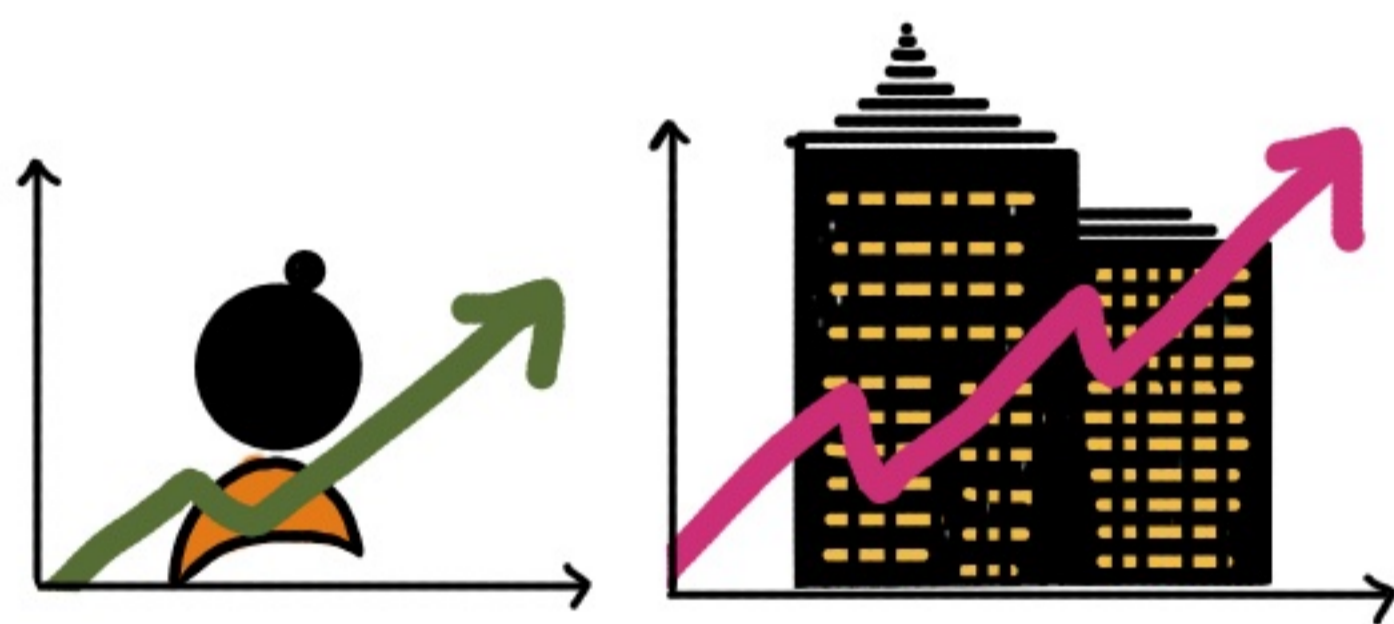COMPUTING DEVICES

STREAMING

APPS/SERVICES

CLOUD COMPUTING

TRAINING AI MODELS

ENTERTAIMENT CONSOLES
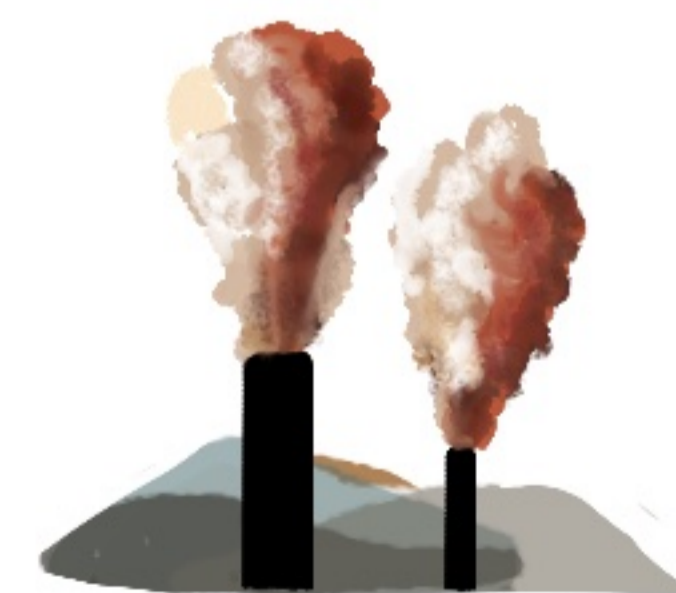
DATA CENTRES

COMMUNICATION NETWORKS

OTHER HARDWARE

THE USES ARE BOTH PERSONAL & COMMERCIAL AND THEY ARE GROWING!

THE EMISSIONS ARE PROJECTED TO BE HIGHER DOUBLE DIGITS BY 2050

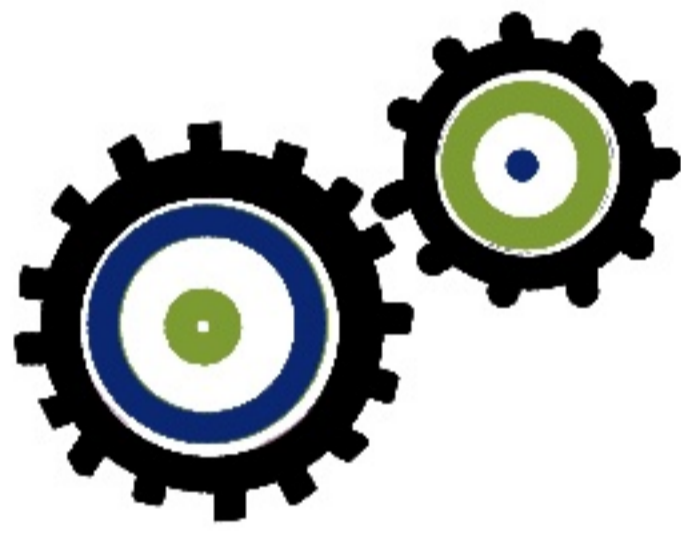THE INDUSTRY RELIES HEAVILY ON ELECTRICITY

MOST GENERATED ELECTRICITY COMES FROM FOSSIL FUELS

GREEN SOFTWARE

GREEN SOFTWARE IS THE RESULT OF PRACTITIONERS CREATING AND DEPLOYING CODE THAT LIMITS ENVIRONMENTAL IMPACT
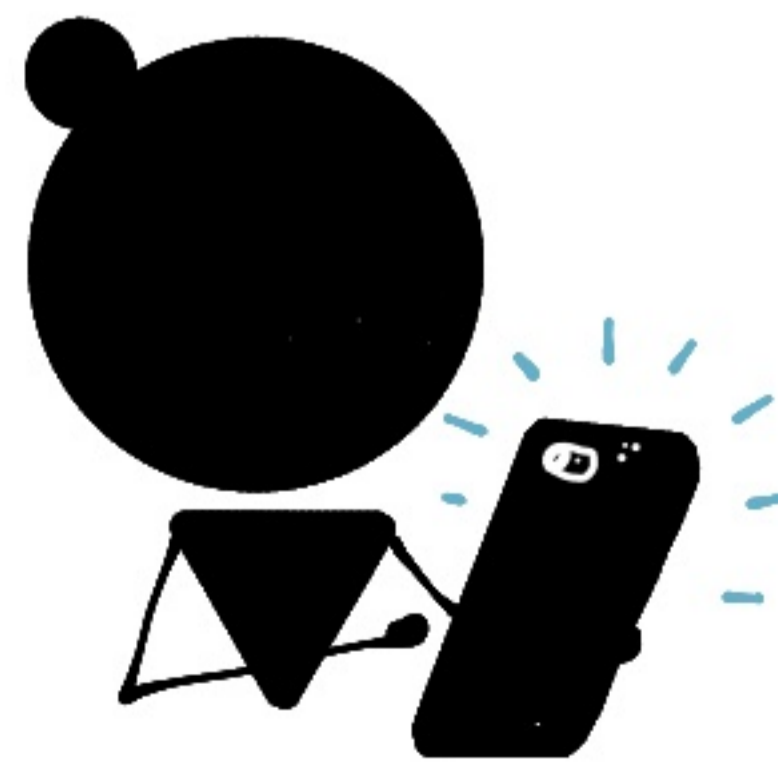
GREEN SOFTWARE TAKES INTO ACCOUNT

SOFTWARE PROCESSES

HARDWARE/ DATA CENTRES

SOFTWARE ARCHITECTURE

END USER

ENERGY SOURCES

A CALL TO ACTION

OUR GOAL AS GREEN SOFTWARE ENGINEERS IS
NOT TO WRITE REPORTS.

IT IS TO IMPLEMENT CHANGE.

- ASIM HUSSAIN

GREEN SOFTWARE FOUNDATION

PRINCIPLES OF GREEN SOFTWARE

8 PRINCIPLES - FROM 2019

① CARBON

REDUCING

CARBON FOOTPRINT

② ELECTRICITY

MAKING SOFTWARE

ENERGY EFFICIENT

③ CARBON INTENSITY

Less CO_2e per kilowatt hour of electricity

BEING LESS
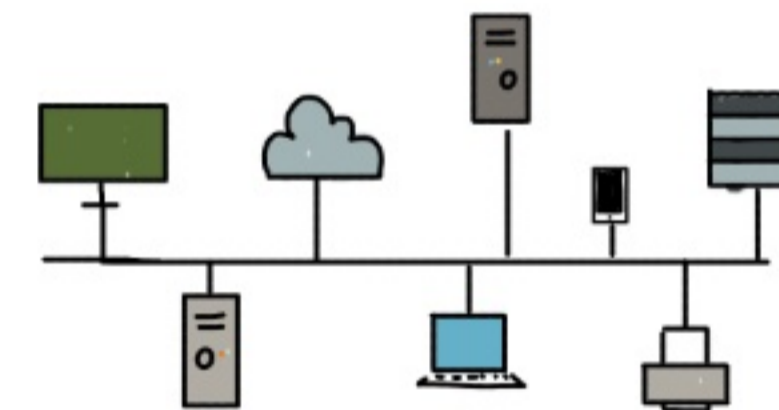
CARBON INTENSIVE

④ EMBODIED CARBON

USING DEVICES

FOR LONGER

⑤ ENERGY PROPORTIONALITY

MAXIMISE

HARDWARE EFFICIENCY

⑥ NETWORKING

REDUCING DATA USED

AND DISTANCE IT TRAVELS

⑦ DEMAND SHAPING

MOVING COMPUTE

DEMANDS TO ANOTHER

TIME OR REGION

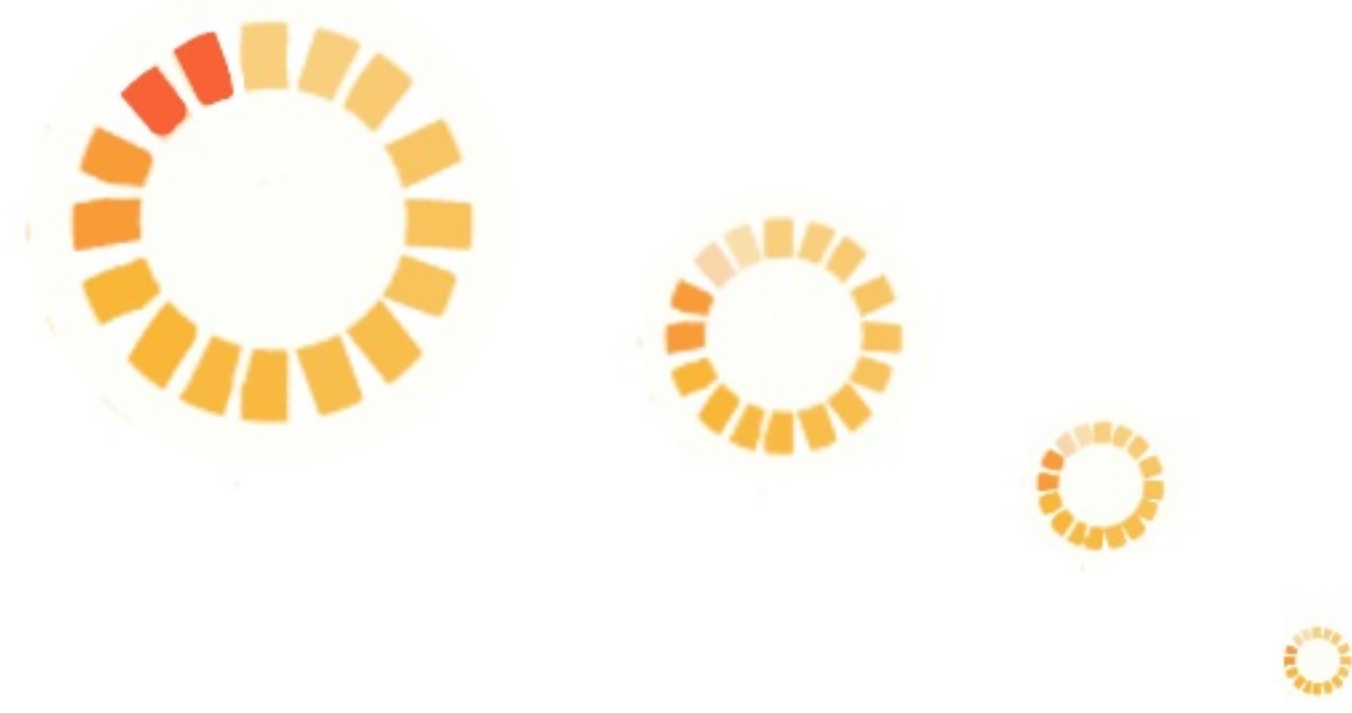## ⑧ MEASUREMENT

MEASURING

AND OPTIMISING

6 PRINCIPLES - UPDATED 2022

CARBON EFFICIENCY

EMITTING THE LEAST POSSIBLE AMOUNT OF CARBON

ENERGY EFFICIENCY

USING THE LEAST POSSIBLE AMOUNT OF ENERGY

CARBON AWARENESS

less
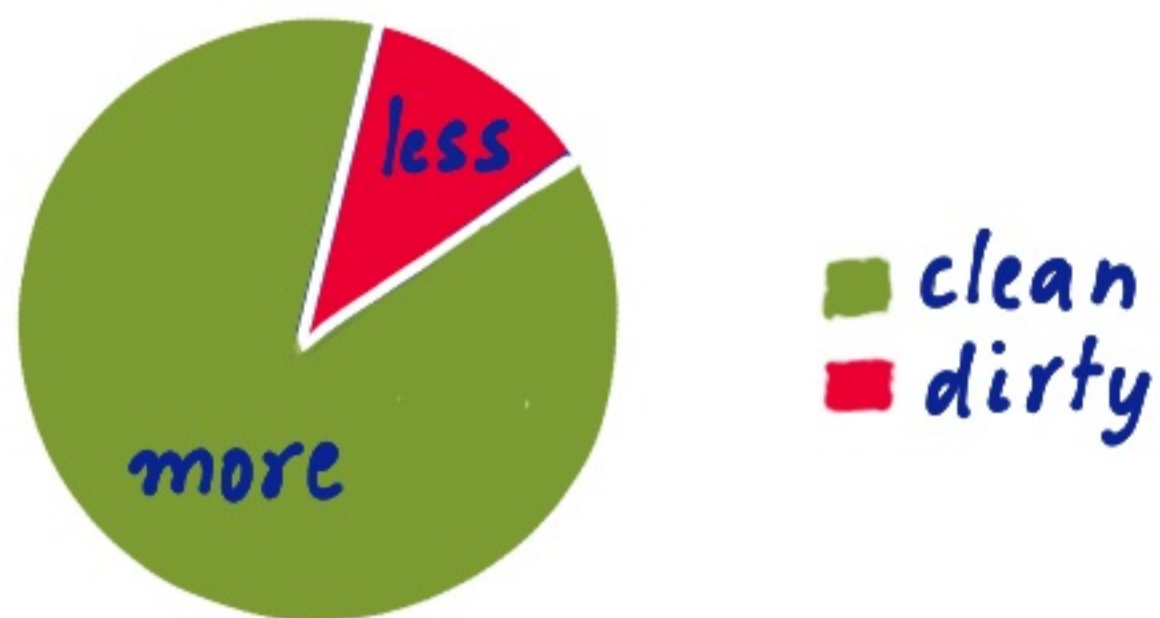
more

clean
dirty

DO MORE WITH CLEAN ENERGY
DO LESS WITH DIRTY ENERGY

HARDWARE EFFICIENCY

?
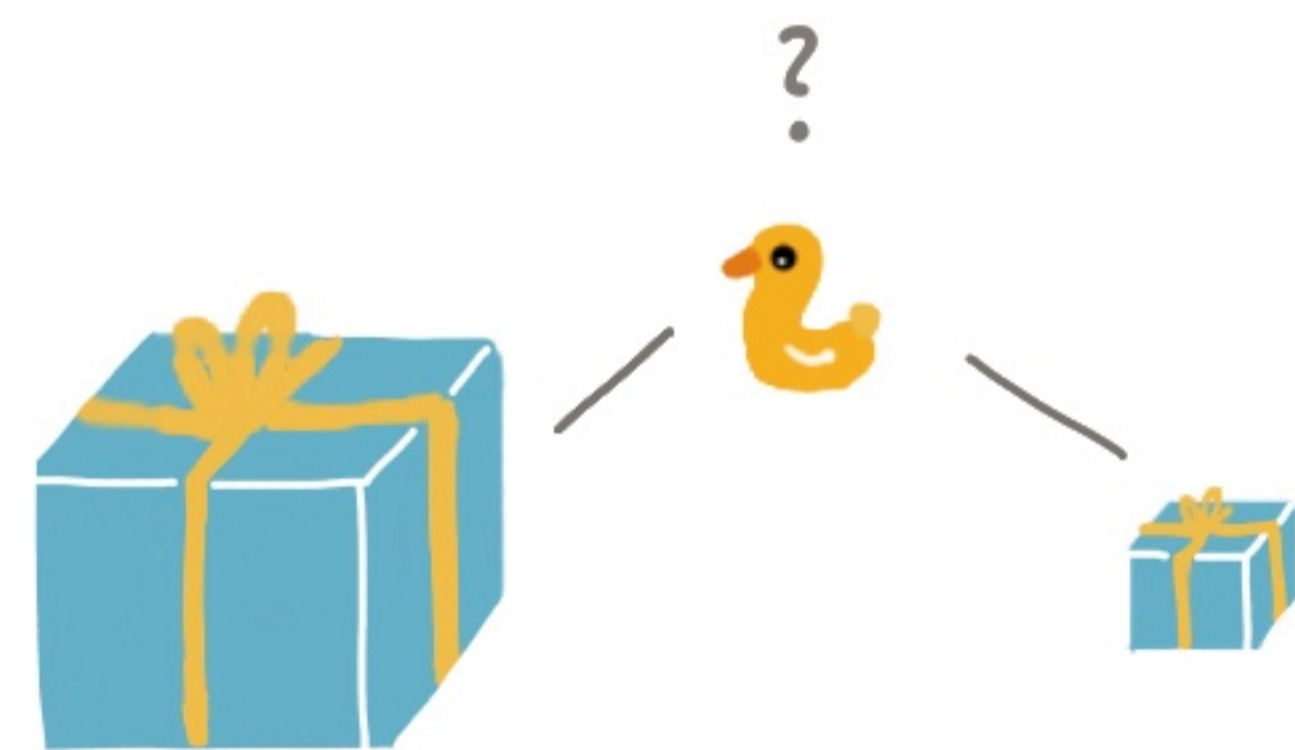
USE THE LEAST POSSIBLE AMOUNT OF EMBODIED CARBON

MEASUREMENT

1 kg   7 kg   3 kg

MEASURE TO IMPROVE

CLIMATE COMMITMENTS

I promise to
☑ reduce
☑ control
☑ prevent
CO2 emissions
in my company

UNDERSTAND CARBON REDUCTION METHODS

① CARBON EFFICIENCY

EMITTING THE LEAST POSSIBLE
AMOUNT OF CARBON

USING CARBON EFFICIENTLY MEANS GETTING THE SAME VALUE
FROM AN ACTIVITY BUT WITH LESS CARBON EMISSIONS.

E.G. TO GET A CAR IN MOTION
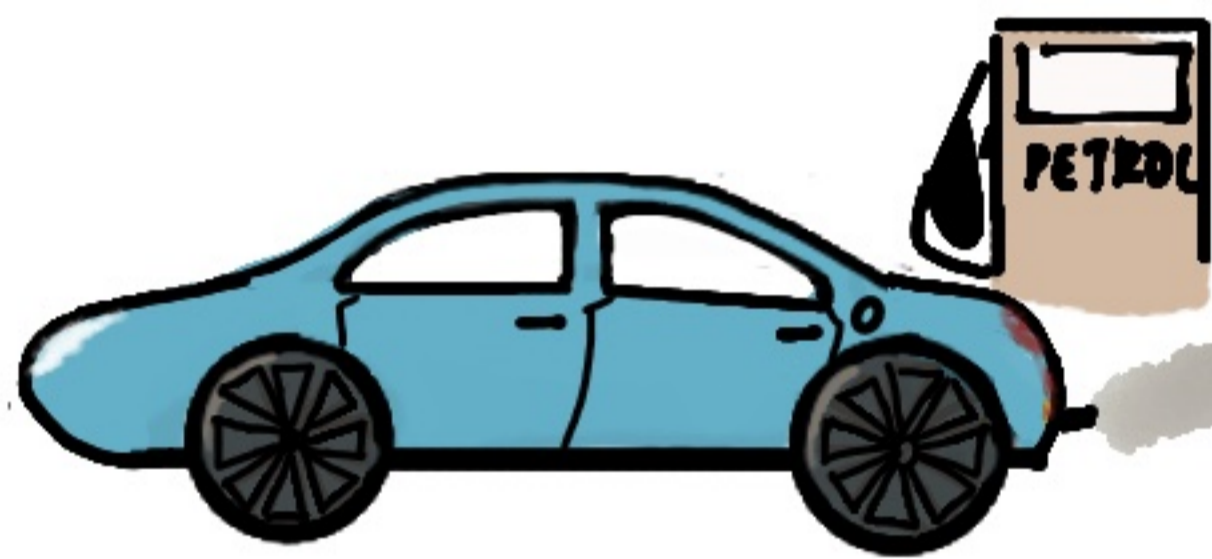
losses from heat, friction

INTERNAL COMBUSTION ENGINE
FUEL EFFICIENCY = UNDER 40%

ELECTRIC VEHICLE
FUEL EFFICIENCY = ~70%

IN FUEL EFFICIENCY, ELECTRIC VEHICLES ARE A LOT BETTER
AT GETTING A CAR TO MOVE — WITH MINIMUM WASTE.

THE PRINCIPLES OF GREEN SOFTWARE ENGINEERING REMIND
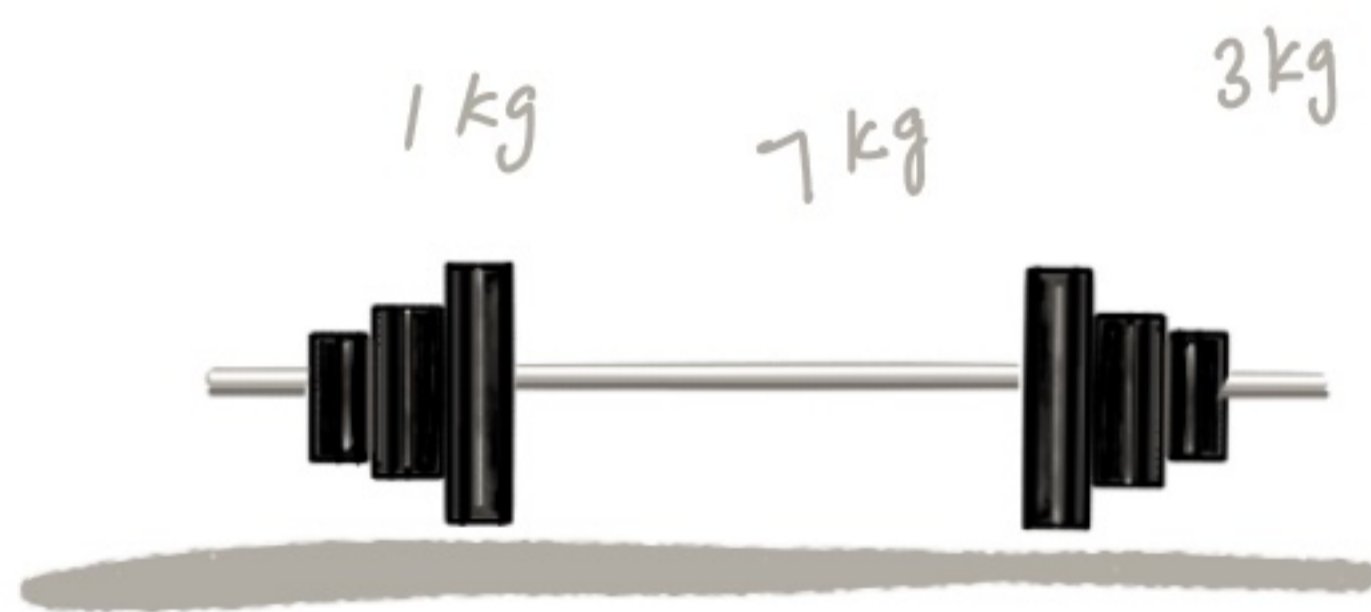US TO BUILD APPLICATIONS WITH THE SAME FUNCTION, BUT
WITH LESS EMISSIONS WHERE POSSIBLE.

② ENERGY EFFICIENCY

USING THE LEAST POSSIBLE
AMOUNT OF ENERGY

ELECTRICITY IS A
PROXY FOR CARBON

WHEN ELECTRICITY
IS CONSUMED

CARBON IS EMITTED

WHEN THIS AMOUNT IS

LOW   HIGH

CARBON
INTENSITY

IS LOW   IS HIGH
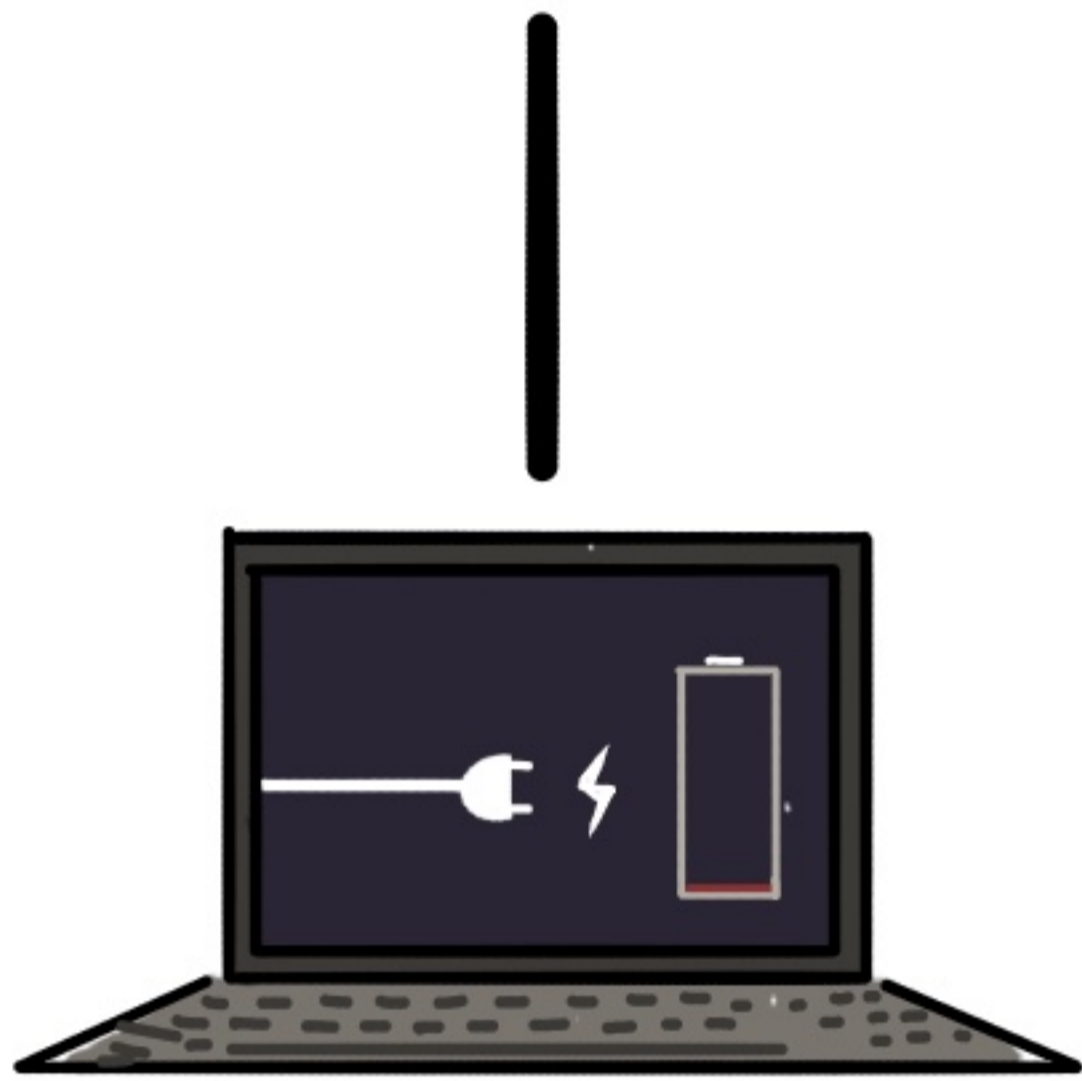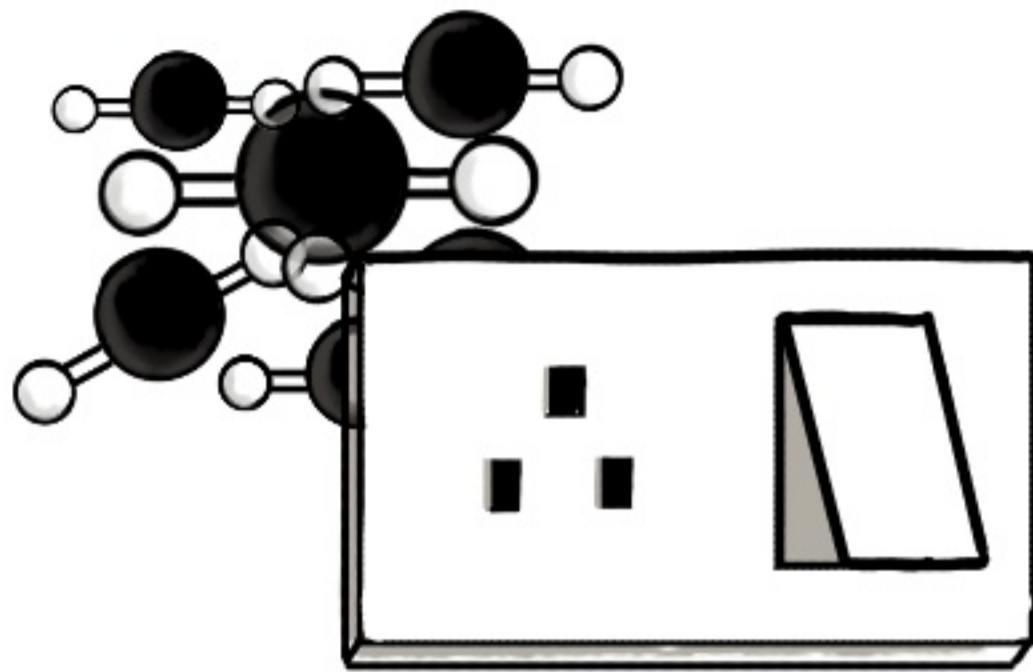
SOFTWARE NEEDS
ELECTRICITY TO RUN

MAKE APPLICATIONS
MORE ENERGY EFFICIENT

CONSUME LESS ELECTRICITY
EMIT LESS CARBON

A MEASURE OF HOW MUCH
CARBON IS EMITTED
WHEN USING ELECTRICITY

TO BE ENERGY EFFICIENT

HERE ARE THREE LINES OF INQUIRY THAT CAN HELP MAKE DECISIONS ON HOW BEST TO USE ENERGY WITH LEAST WASTE

HOW MUCH POWER IS USED FOR COMPUTE?

POWER USAGE EFFECTIVENESS

WHEN IDLE, HOW MUCH ELECTRICITY DO THE PARTS CONSUME?

STATIC POWER DRAW

WHAT IS THE RELATIONSHIP OF POWER CONSUMED TO UTILISATION?
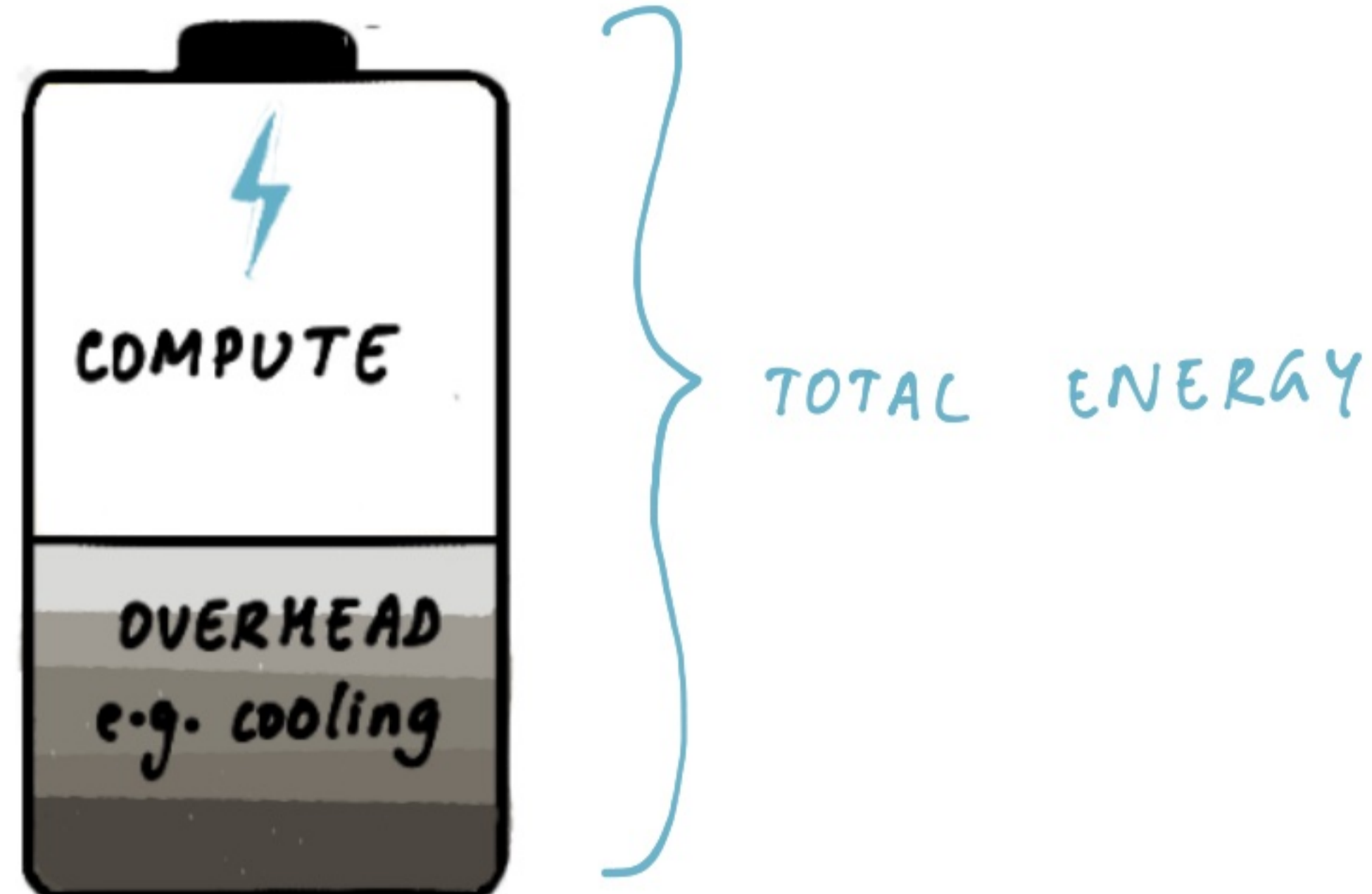
ENERGY PROPORTIONALITY

POWER USAGE EFFECTIVENESS

HOW MUCH POWER IS USED FOR COMPUTE?

TOTAL ENERGY

PUE = POWER USAGE EFFECTIVENESS

$$PUE \ IN \ DATA \ CENTRES = \frac{TOTAL \ ENERGY}{ENERGY \ FOR \ COMPUTE}$$

THERE ARE ENERGY EFFICIENCY GAINS
FOR PUE OF 1.0 TO 1.2

DEPENDING ON THE TYPE OF DATA CENTRE
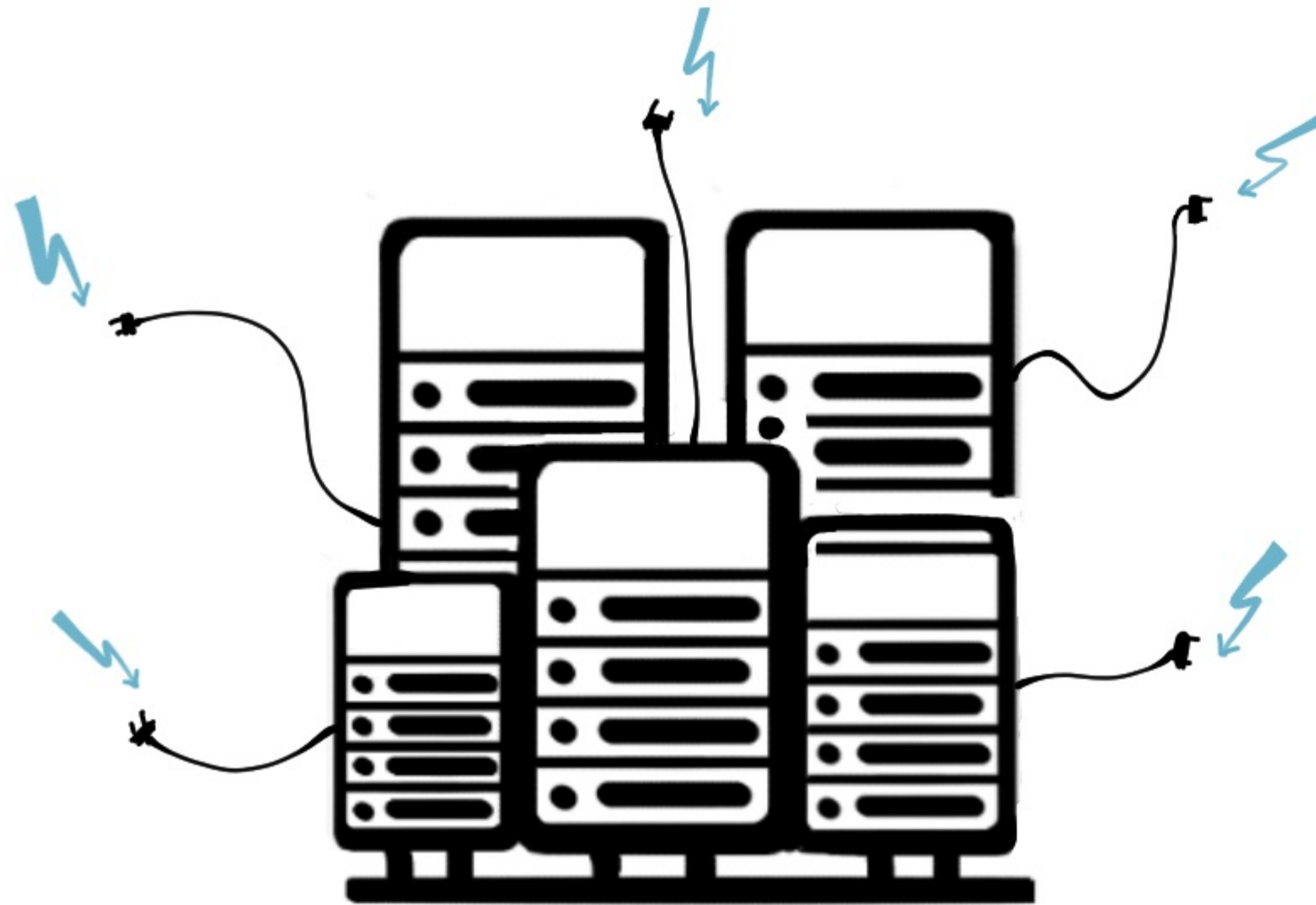PUE OF ~1.4 COULD BE INEFFICIENT

STATIC POWER DRAW

WHEN IDLE, HOW MUCH ELECTRICITY DO THE PARTS CONSUME?

TO SAVE ELECTRICITY, DEVICES HAVE POWER SAVE MODES

IDLE STATE ≠ POWER SAVE/STAND BY MODES

POWER SAVE MODES = SLOW RESTARTS

SLOW RESTARTS = SLOW RESPONSE TO DEMANDS

THE CHOICE IS EITHER SAVE ELECTRICITY OR RESPOND QUICKLY TO CHANGING DEMANDS

ENERGY PROPORTIONALITY

THIS ANSWERS THE QUESTION:

WHAT IS THE RELATIONSHIP OF POWER CONSUMED TO UTILISATION?

THIS RELATIONSHIP IS A CONSTANT IN ENERGY PROPORTIONAL SYSTEMS HOWEVER, ON OBSERVATION, THIS IS NOT HOW HARDWARE WORKS

POWER

200W
180W

static
power
draw → 100 W

0%   50%   100%   UTILISATION
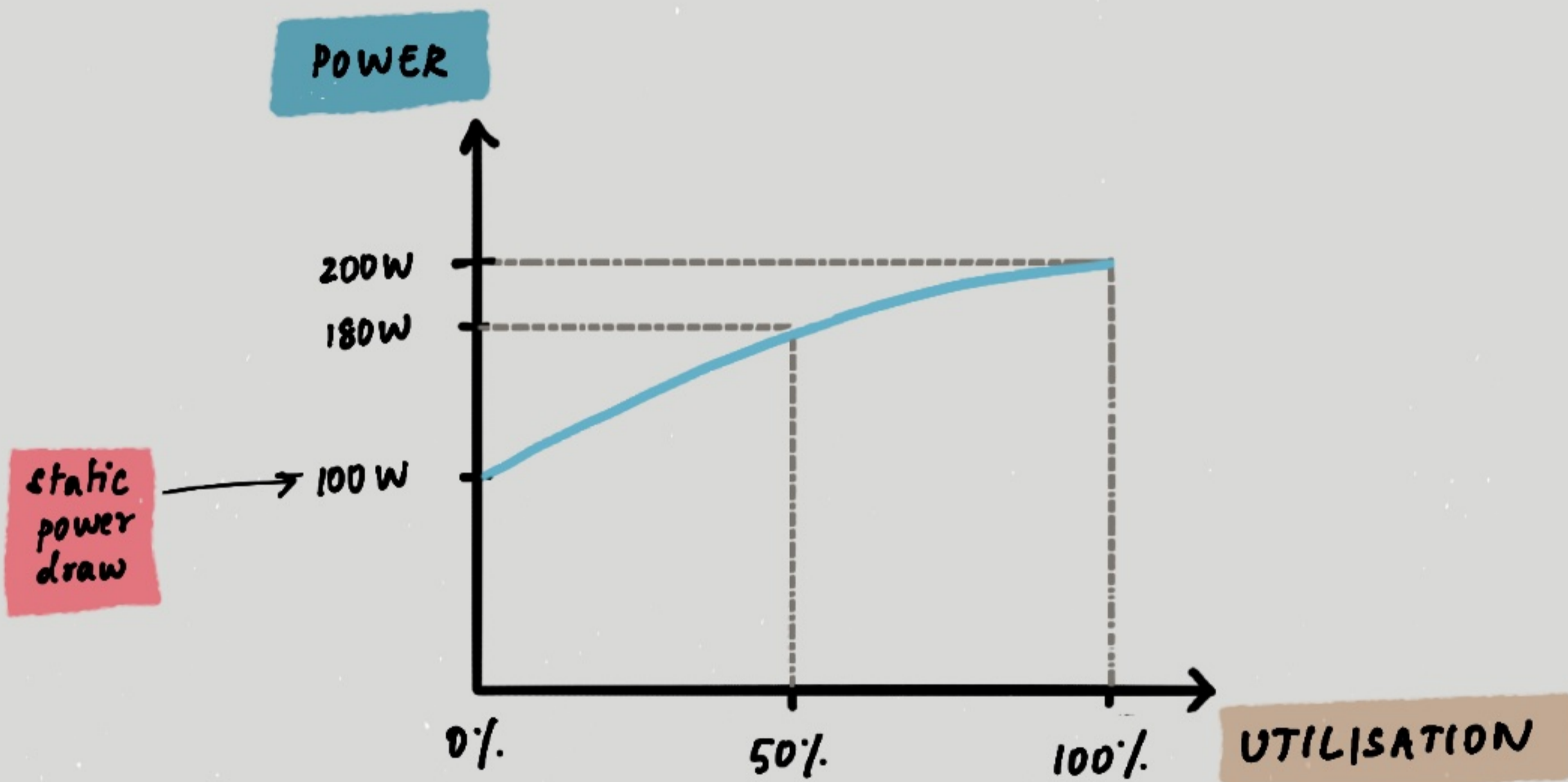
Source: green software foundation on Energy Efficiency

UTILISATION IS WHAT % OF COMPUTING RESOURCES ARE USED

POWER DRAWN DOES NOT INCREASE IN PROPORTION TO UTILISATION

THE HIGHER THE UTILISATION, THE MORE EFFICIENT IT BECOMES

FEWER SERVERS AT HIGH UTILISATION RATE IS ENERGY EFFICIENT

③ CARBON AWARENESS

DO MORE WITH CLEAN ENERGY

DO LESS WITH DIRTY ENERGY
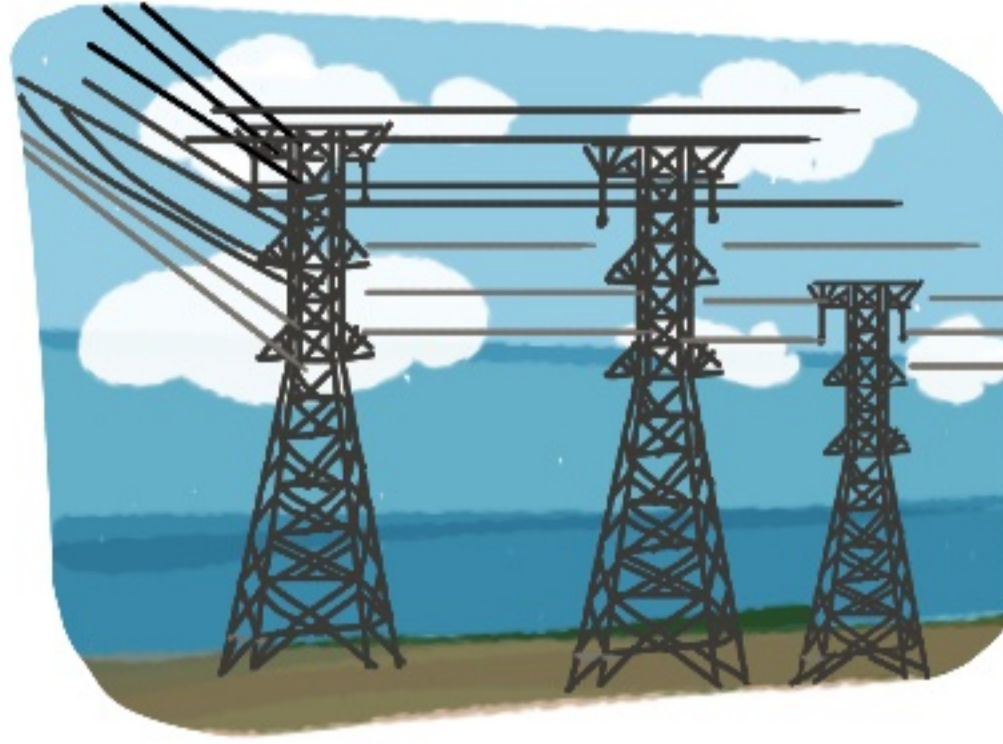
A POWER GRID IS A NETWORK OF CABLE + EQUIPMENT TO SUPPLY ELECTRICITY FROM VARIOUS SOURCES

HIGH CARBON SOURCES

LOW CARBON SOURCES

A GRID'S CARBON INTENSITY VARIES BY

SUPPLY / TIME / LOCATION

CARBON-AWARE APPLICATIONS REACT TO THE CARBON INTENSITY OF THE GRID BY CHANGES IN ENERGY DEMANDS

TO BE CARBON-AWARE

RENEWABLE ENERGY SOURCES ARE INCREASINGLY BEING USED AS THEY ARE GETTING CHEAPER.

SO HERE ARE TWO CARBON-AWARE APPROACHES
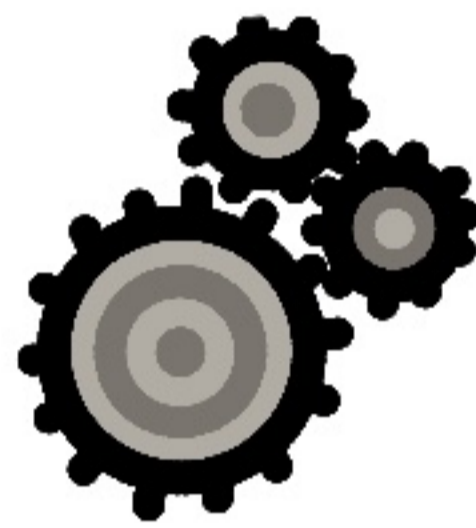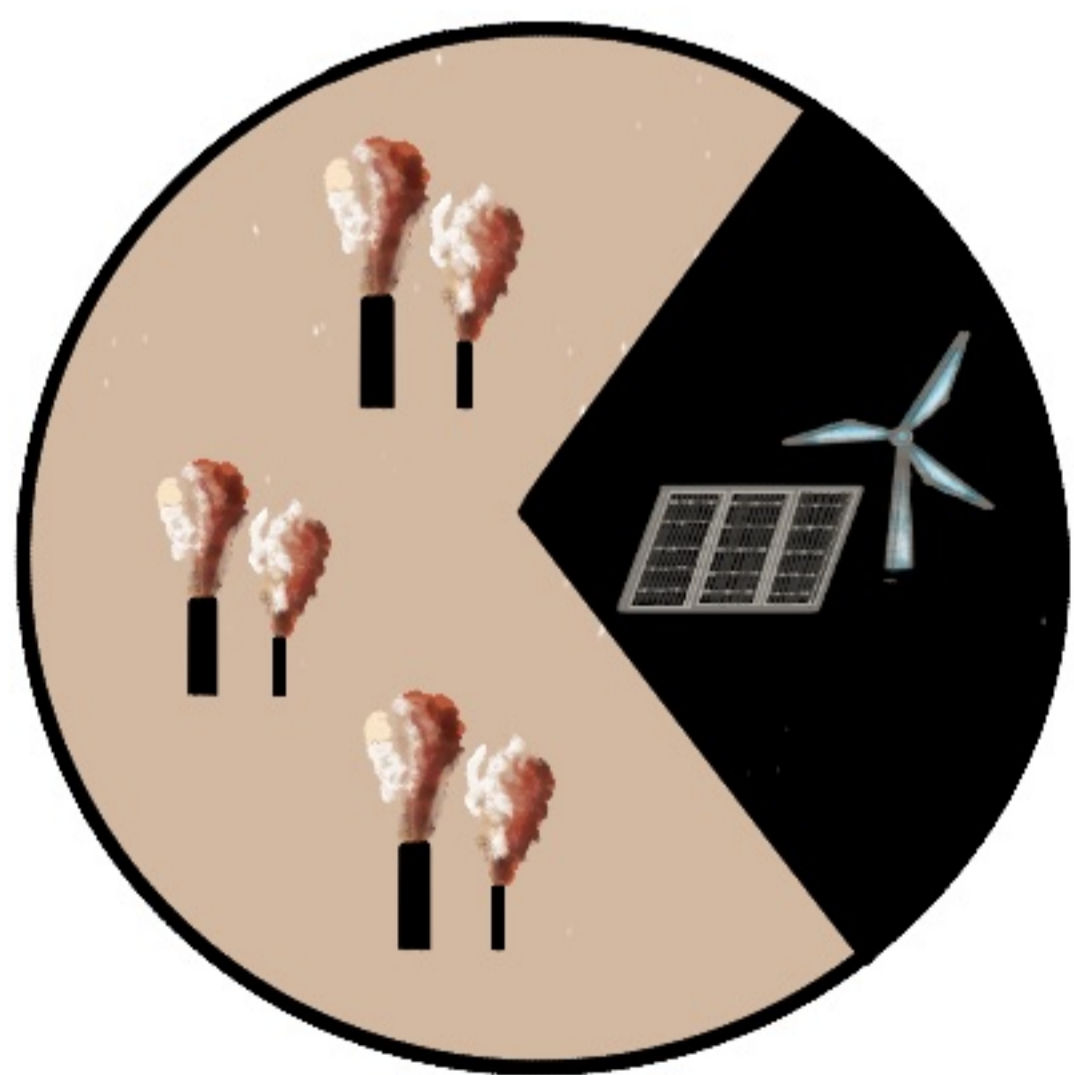
DEMAND SHIFTING

BEING FLEXIBLE ABOUT

WHEN

WHERE

TO RUN

WORKLOADS

BATCH JOBS

SOFTWARE UPDATES

CRITICAL TASKS

LOW PRIORITY TASKS

MACHINE LEARNING

CALCULATIONS PRE-DONE
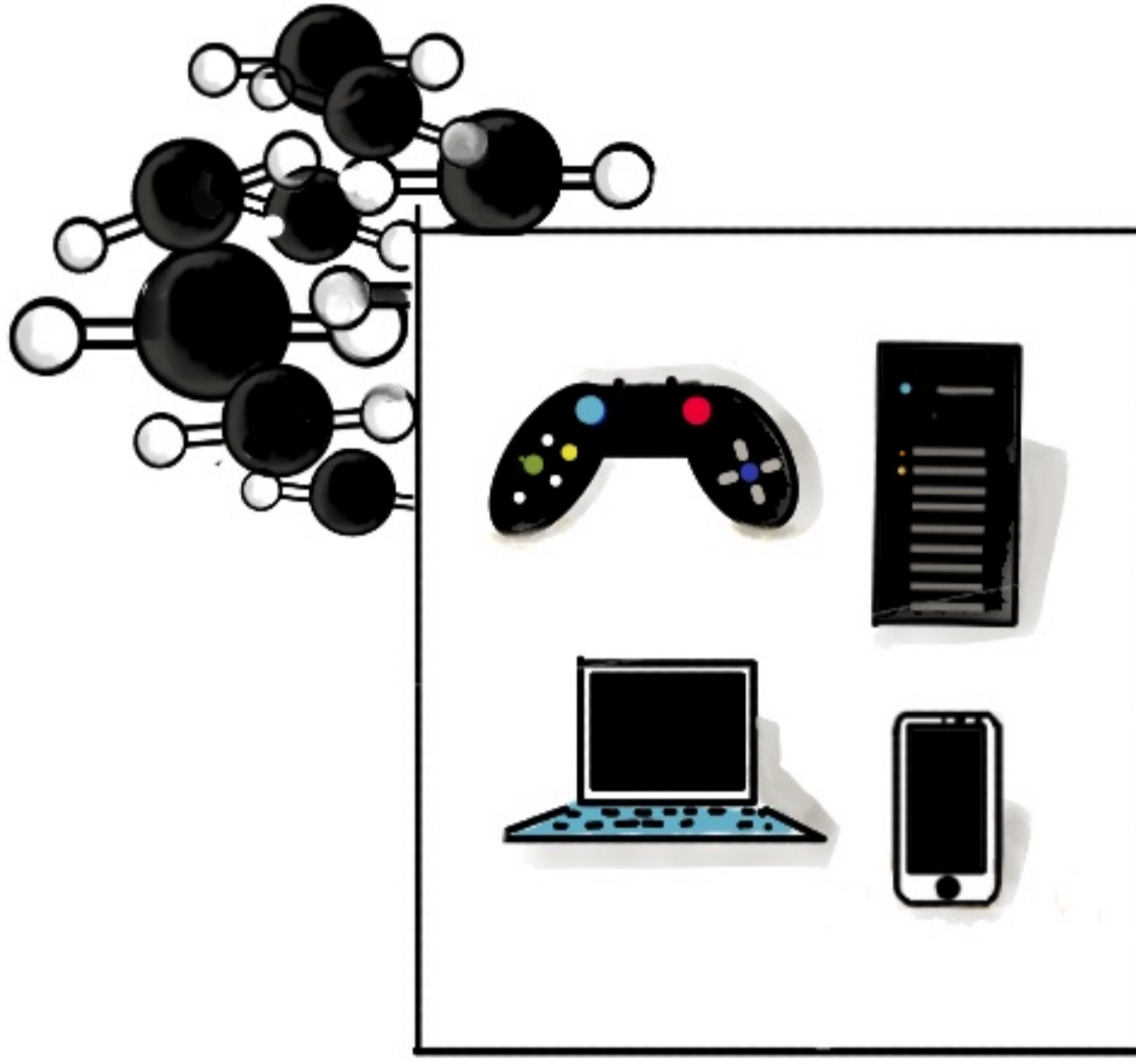
DATA/CALC CACHING

DEMAND SHAPING

BEING FLEXIBLE

ABOUT WHAT WORKLOADS RUN

ECO MODES — AUTO/MANUAL

GRACEFUL DEGRADATION

CANCELLING JOBS

REDUCING CONSUMPTION

WHEN SUPPLY OF CARBON/RENEWABLES VARIES

4 HARDWARE EFFICIENCY

USE THE LEAST POSSIBLE
AMOUNT OF EMBODIED CARBON

HARDWARE IS A
PROXY FOR CARBON
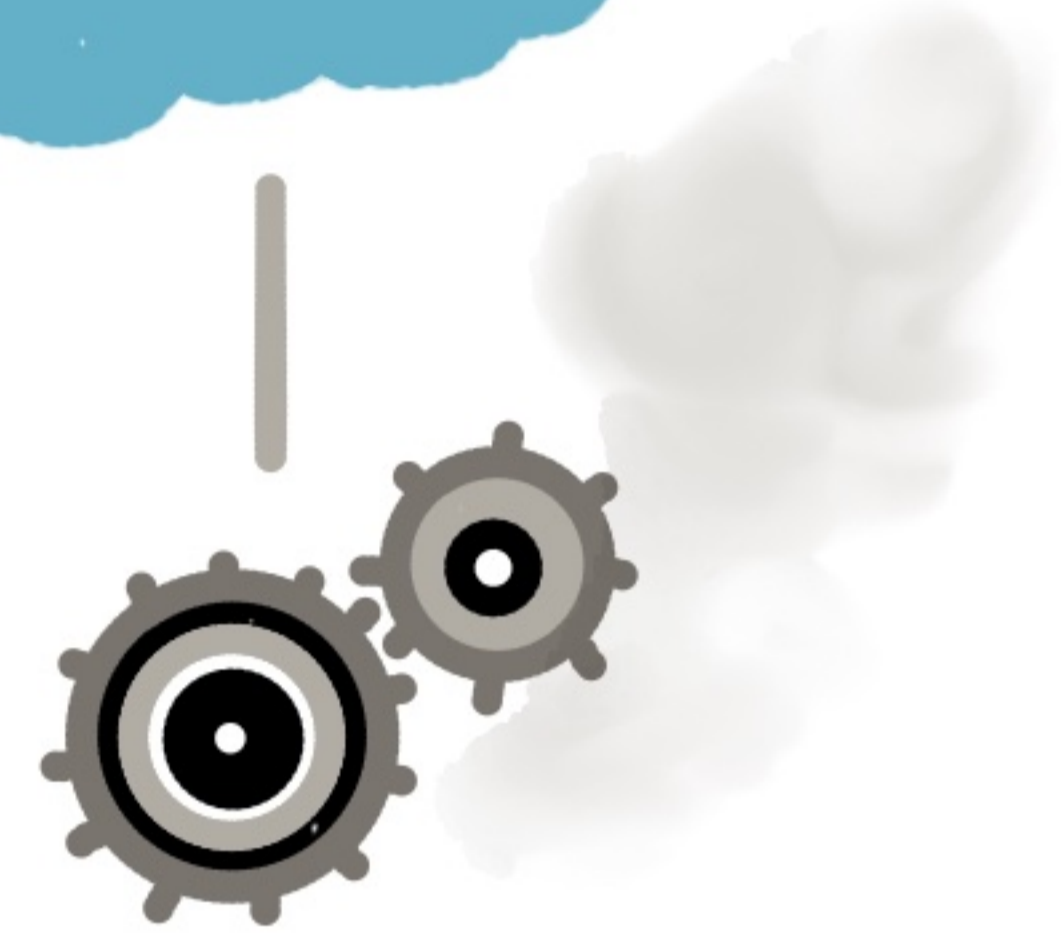
DEVICES EMIT CARBON
WHEN THEY ARE IN USE

THE MANUFACTURING PROCESS
FOR EACH DEVICE
EMITS CARBON

FOR SOME, THE EMBODIED
CARBON IS FAR HIGHER

MAKE HARDWARE EFFICIENT

THE END-OF-LIFE PROCESS
ALSO EMITS CARBON
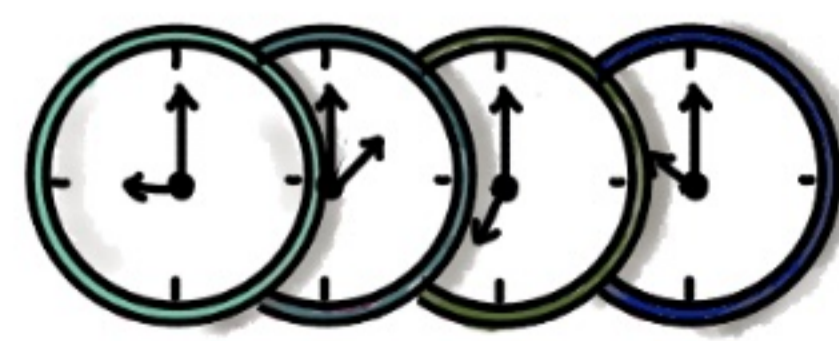
USE IT
MORE

USE IT
LONGER

THIS EMITTED CARBON AT
CREATION & DISPOSAL IS
EMBODIED CARBON

TO BE HARDWARE EFFICIENT

USE IT MORE — UTILISATION

HARDWARE EFFICIENCY IN THE CLOUD IS ABOUT UTILISATION
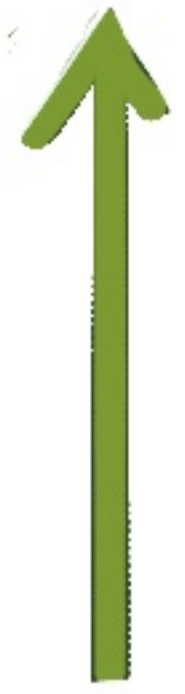
1 SERVER AT 100% UTILISATION IS BETTER THAN
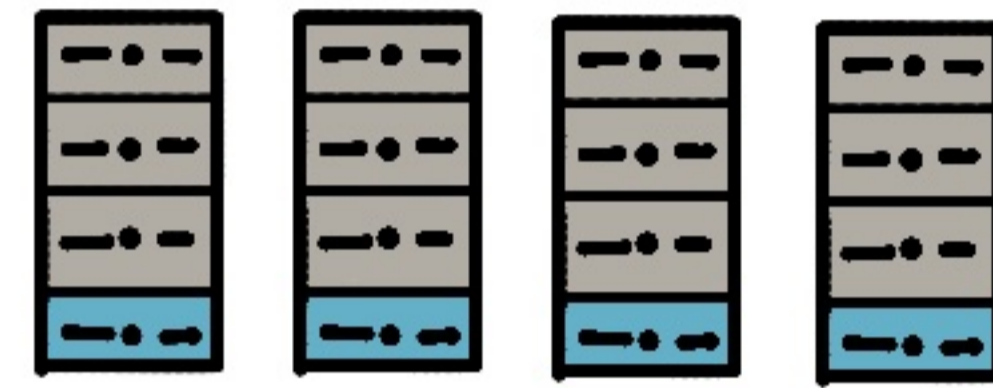
4 SERVERS AT 25% UTILISATION

CLOUD SERVERS CAN PERFORM

✓ DEMAND SHIFTING

✓ DEMAND SHAPING

THEREFORE ARE MORE ENERGY EFFICIENT THAN ON-PREMISE

TO BE HARDWARE EFFICIENT

IN ACCOUNTING FOR EMBODIED CARBON, WE AMORTISE (WRITE OFF) THE CARBON OVER THE ESTIMATED DEVICE-LIFETIME
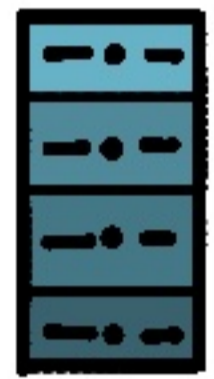
IT TAKES 80 kg CO_2 eq TO MAKE A SMARTPHONE WHICH COULD LAST 4 YEARS

THE PHONE EMITS 20 kg CO_2 eq / YEAR

IF SOFTWARE UPDATES COULD RUN THE PHONE (HARDWARE) FOR JUST ONE MORE YEAR 2024

THIS NUMBER DROPS TO 16 kg CO_2 / YEAR

✓ MOVE AWAY FROM PLANNED OBSOLESCENCE

IS EFFICIENCY WASTEFUL?

BY WHATEVER MEANS ENERGY EFFICIENCY OR HARDWARE
EFFICIENCY IS GAINED, A QUESTION IS ASKED

DOES EFFICIENCY CAUSE WASTEFULNESS?

EXAMPLE OF COAL USAGE

WILLIAM STANLEY JEVON, AN
ECONOMIST, NOTICED THIS.

AS STEAM ENGINES GOT MORE
EFFICIENT USING COAL,
MORE COAL WAS USED IN BRITAIN
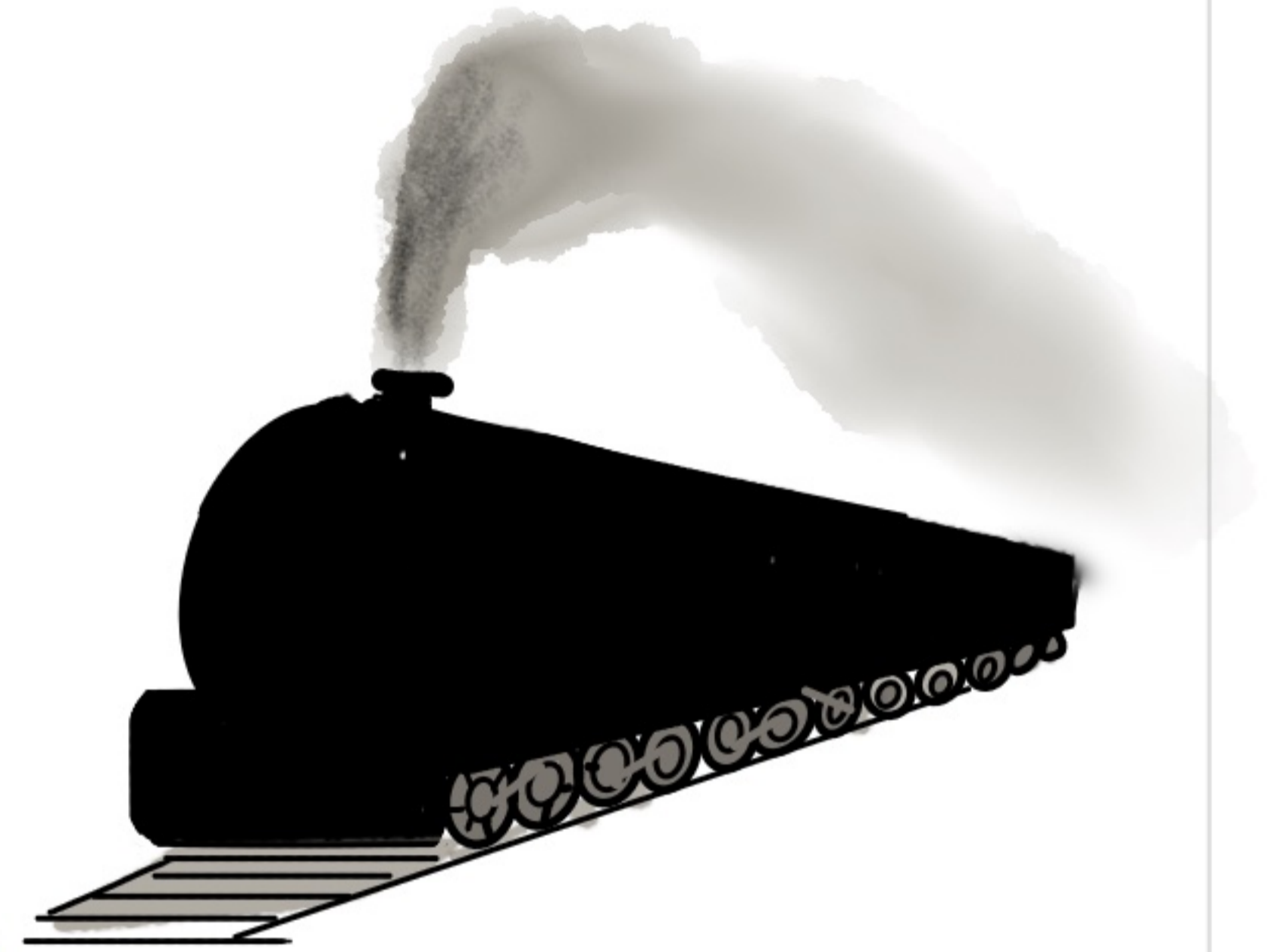
EXAMPLE OF VEHICLE USAGE

THE FUEL EFFICIENCY
OF CARS/AIRLINES HAS
LED TO PEOPLE USING
THEM MORE OFTEN

THE EFFICIENCY + LOWER COST PER MILE (RELATIVELY)
ENDS UP WITH MUCH MORE FUEL BEING CONSUMED

JEVON'S PARADOX

AN INCREASE IN EFFICIENCY IN RESOURCE USE
WILL RESULT IN AN INCREASE (NOT A DECREASE)
IN RESOURCE CONSUMPTION - IN THE LONG TERM

JEVON'S PARADOX AND ITS IMPACT ARE WIDELY DEBATED

Short term

HIGH DEMAND FOR THING

medium term

IMPROVED EFFICIENCY OF THING

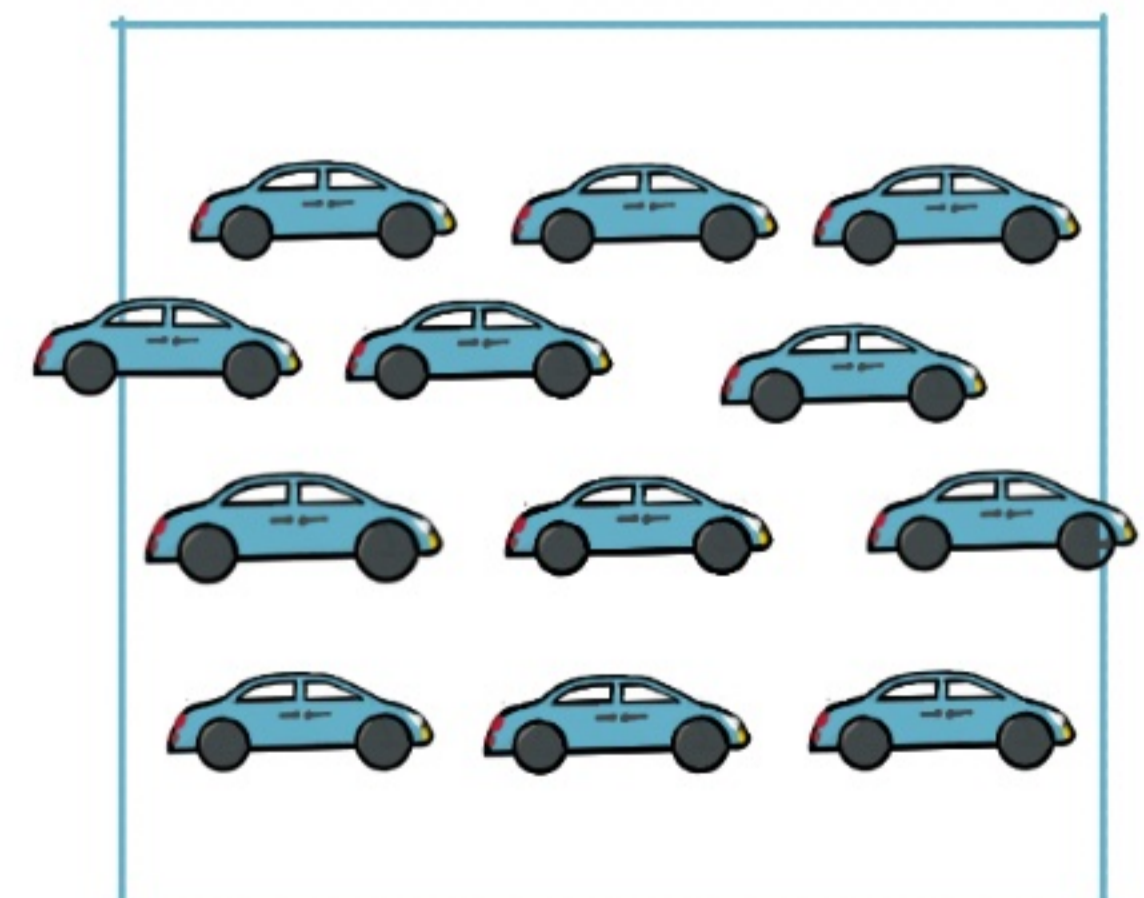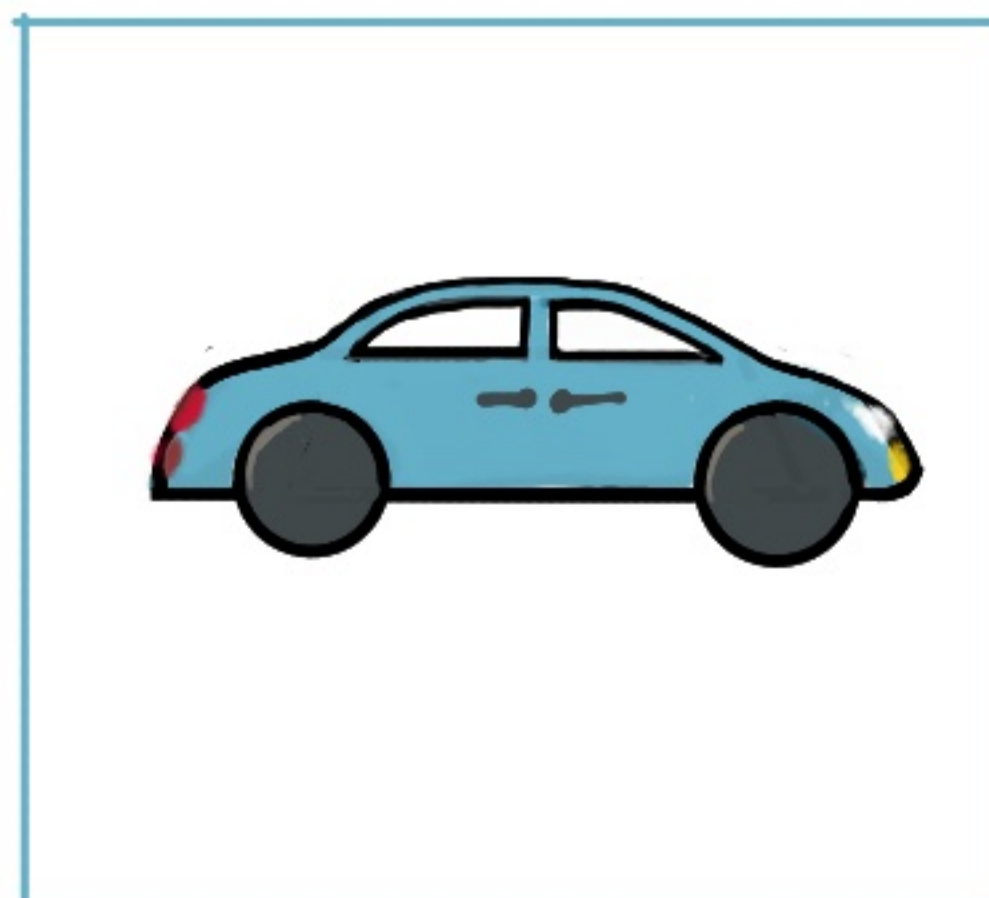→ AS THE RESOURCE GETS CHEAPER

long term

INCREASE IN CONSUMPTION OF THING
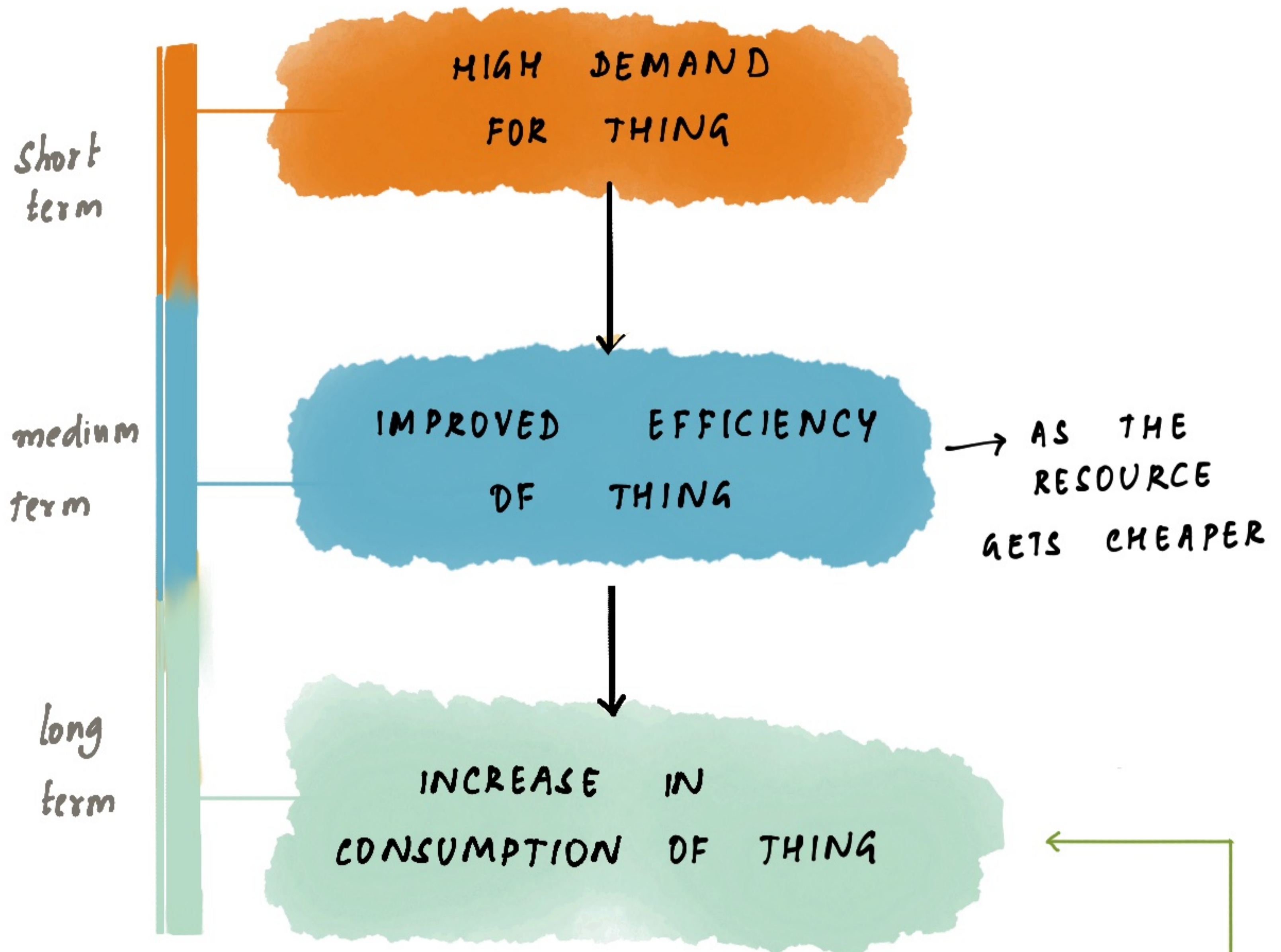
WHILE SOLVING THE CLIMATE CRISIS, IT MIGHT BE WISE TO
MITIGATE THE EFFECTS BY INTERVENTIONS SUCH AS

✓ GREEN TAXES   *before this happens*

✓ CONSERVATION POLICIES TO INCREASE COSTS

SEEKING ENERGY EFFICIENCY PARADOXICALLY WILL RESULT IN
MORE, NOT LESS, CARBON EMISSIONS IF WE ARE CARELESS

⑤ MEASUREMENT

MEASURE TO IMPROVE

CREATING

DISPOSING

OPERATING

EXTRACTING MATERIALS

PROCESSING

TRANSPORT
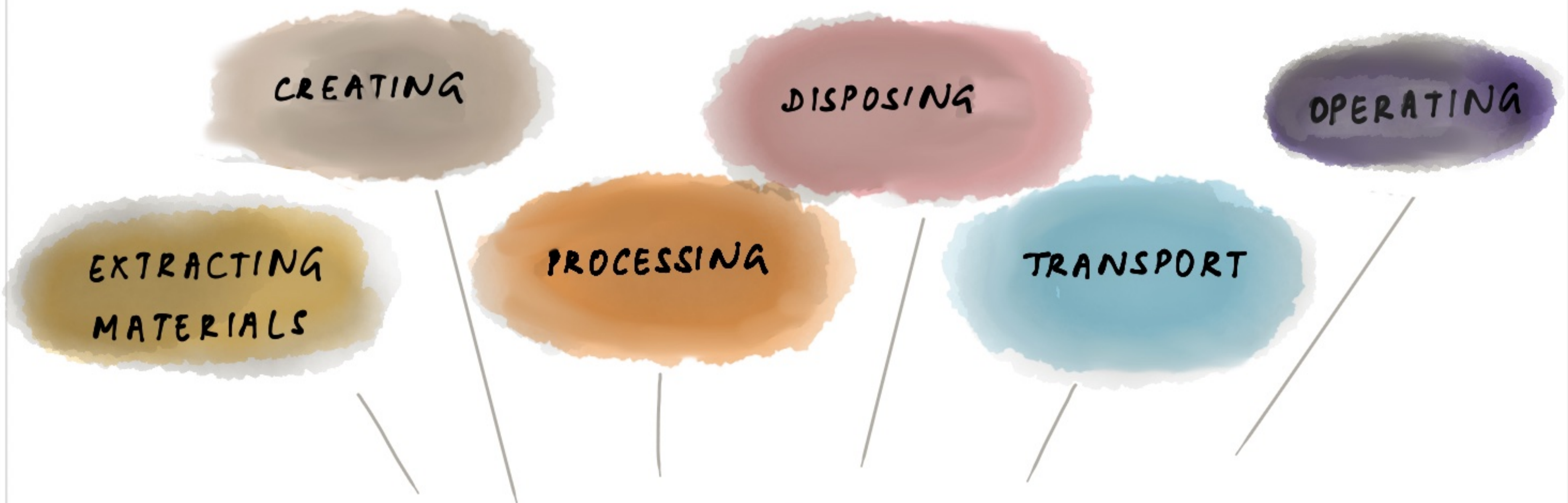
EACH STAGE OF ACTIVITY IN AN ORG/PRODUCT EMITS CARBON

MEASURING CARBON EMISSIONS ACCURATELY IS A CHALLENGE

AS ANY APPROACH COMES WITH ASSUMPTIONS OR INACCURACIES

TWO COMMON APPROACHES ARE

GREENHOUSE GAS (GHG) PROTOCOL

SOFTWARE CARBON INTENSITY (SCI)

USEFUL TO MEASURE EMISSIONS AT AN ORGANISATION LEVEL

USEFUL TO MEASURE SOFTWARE RELATED EMISSIONS

USE MORE THAN ONE METRIC - THERE ARE OTHERS

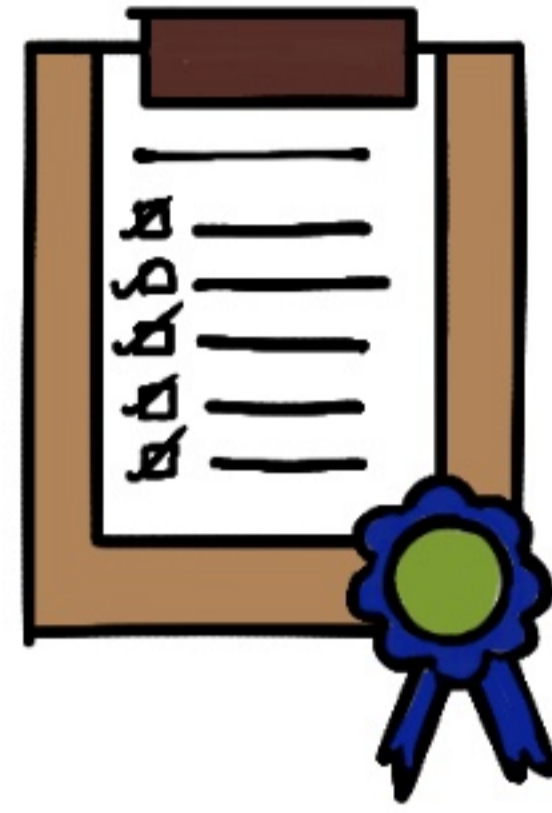# GHG PROTOCOL
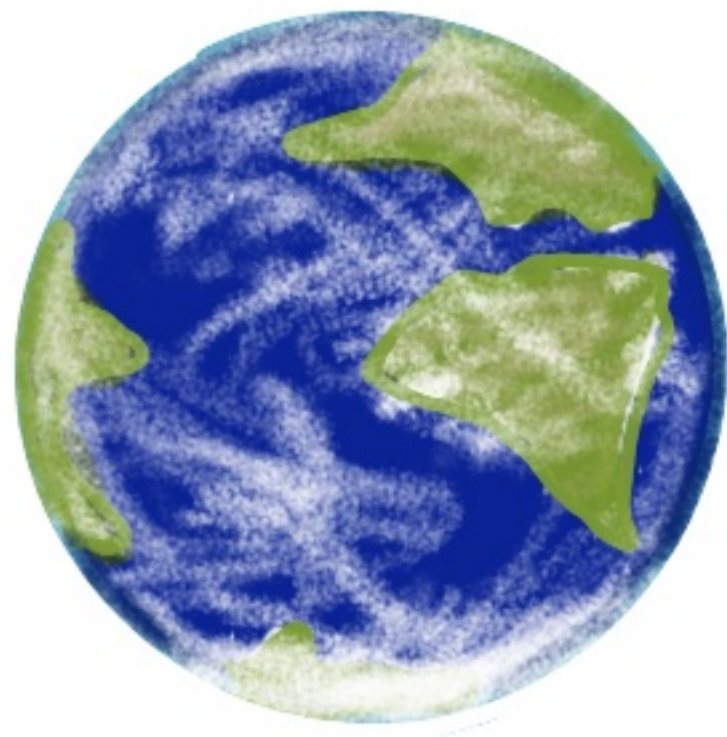
A GLOBAL

STANDARD

FRAMEWORK

- GUIDANCE
- TOOLS
- TRAINING
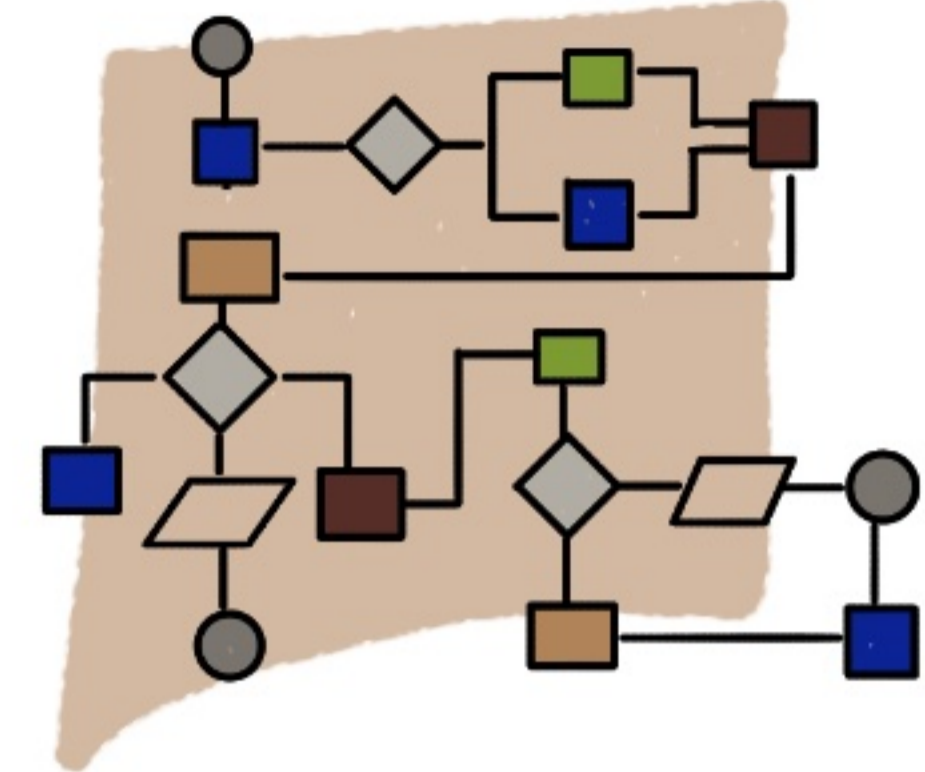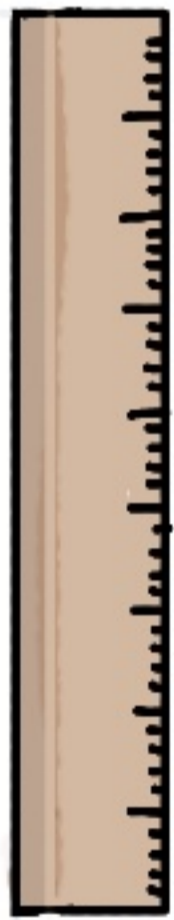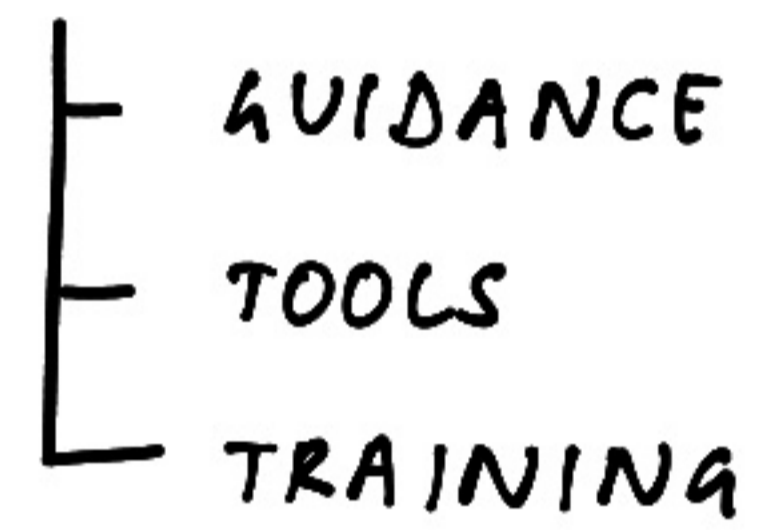
TO MEASURE AND
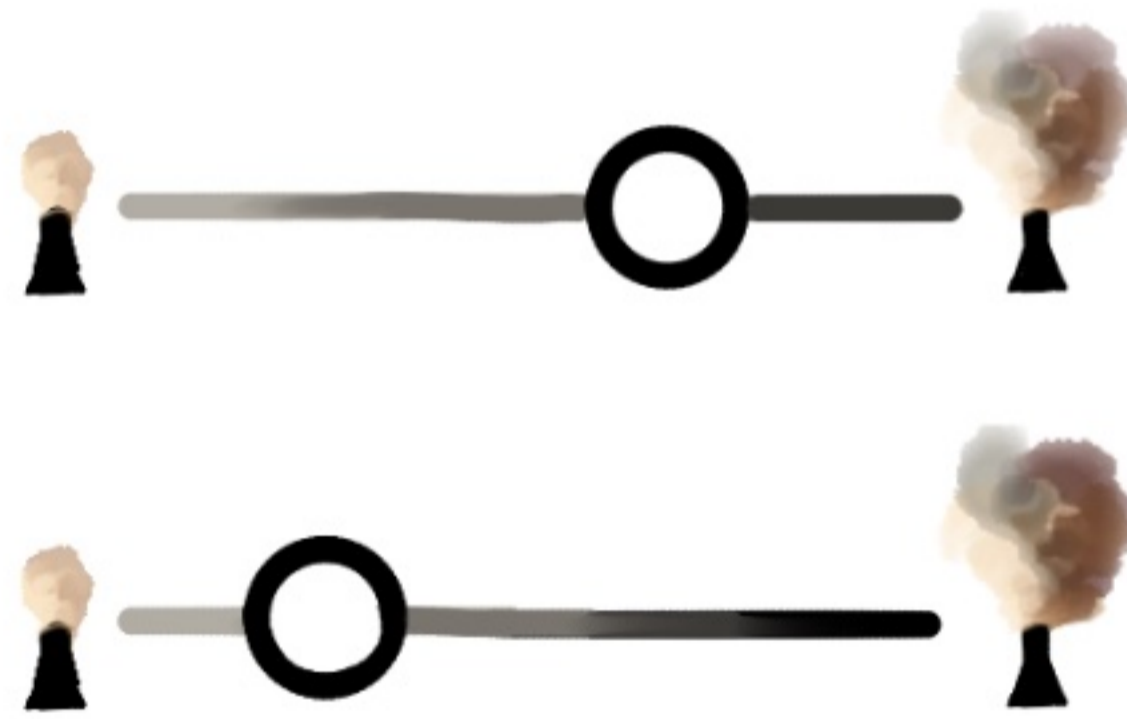
MANAGE EMISSIONS IN
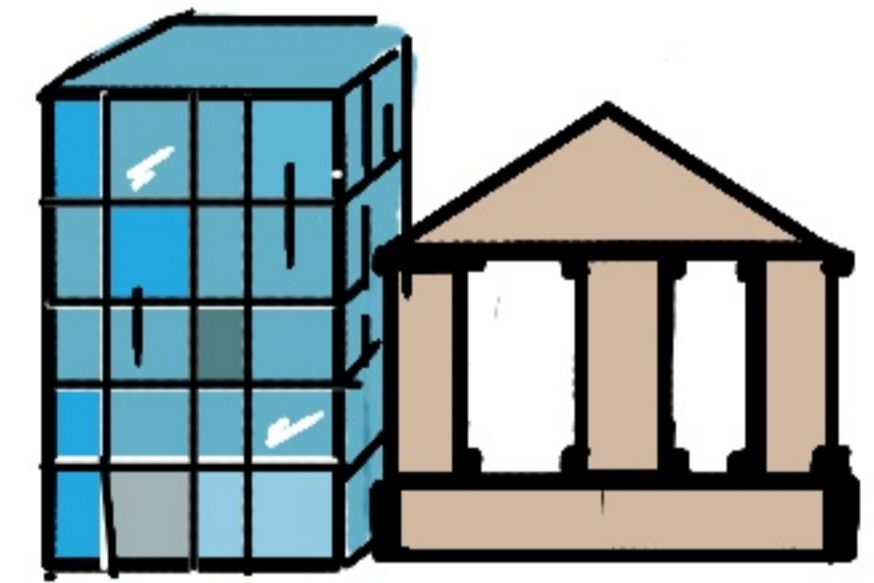
PRIVATE & PUBLIC SECTORS

SCOPE 1 2 3 EMISSIONS

SCOPE 1 EMISSIONS

DIRECT EMISSIONS FROM ORGANISATION-OWNED FACILITIES
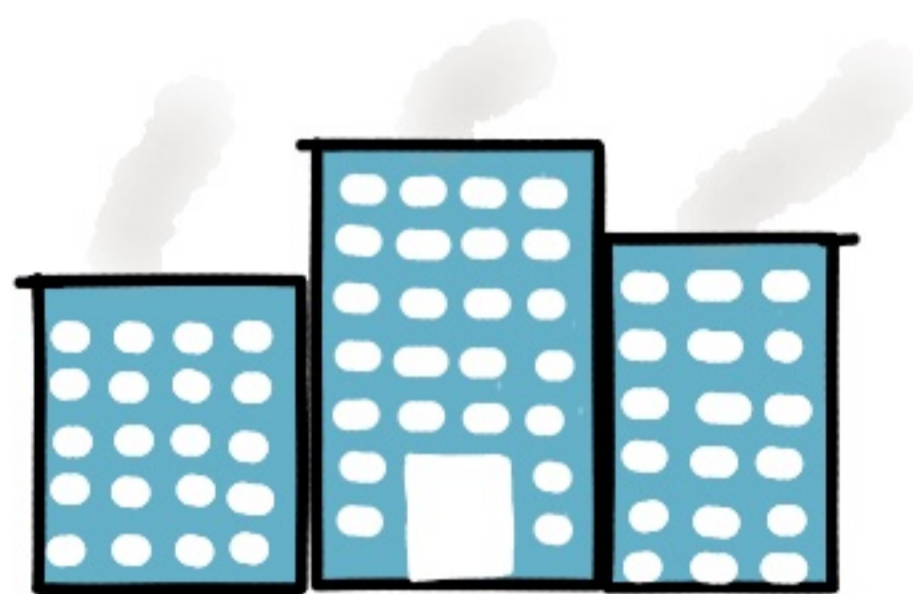
- FUEL BURNED
- LEAKED GASES FROM COOLING/AIR-CON

SCOPE 2 EMISSIONS

INDIRECT EMISSIONS FROM SERVICES PURCHASED
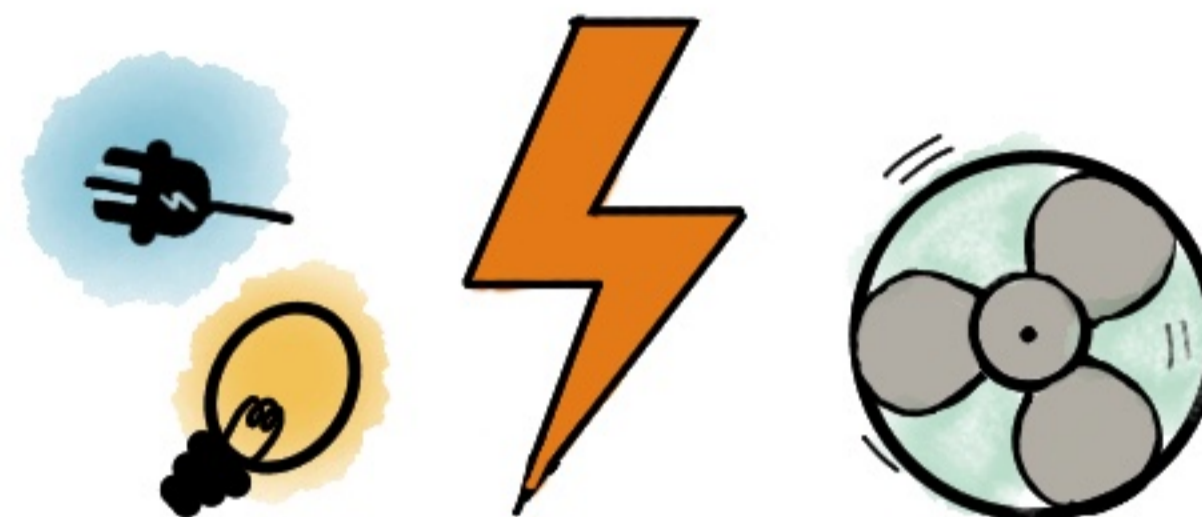
- ELECTRICITY
- HEATING/COOLING

SCOPE 3 EMISSIONS

EMISSIONS ALONG THE ENTIRE VALUE CHAIN

SUPPLIERS TO CUSTOMERS OUTSIDE OF THE ORGANISATION'S CONTROL

UPSTREAM   DOWNSTREAM

COMMUTE   CAPITAL GOODS   PROCESSING
WASTE   DISTRIBUTION   END OF LIFE

NOTES

- GHG PROTOCOL·ORG DEFINED SCOPE 1 2 3
- SCOPE 3 IS THE LARGEST OF THE EMISSIONS AND THE HARDEST TO MEASURE AND REDUCE

GHG PROTOCOL

WORLD RESOURCES INSTITUTE

PARTNERSHIP

WORLD BUSINESS COUNCIL FOR SUSTAINABLE DEVELOPMENT

CREATED

GHG PROTOCOL — 1998

STANDARDS USED BY

- GOVERNMENTS
- NGOs
- INDUSTRY ASSOCIATIONS
- BUSINESSES

PROVIDES METHODS FOR

- ACCOUNTING (SCOPE 1 2 3 EMISSIONS)
- REPORTING
- INVENTORY
- MITIGATION
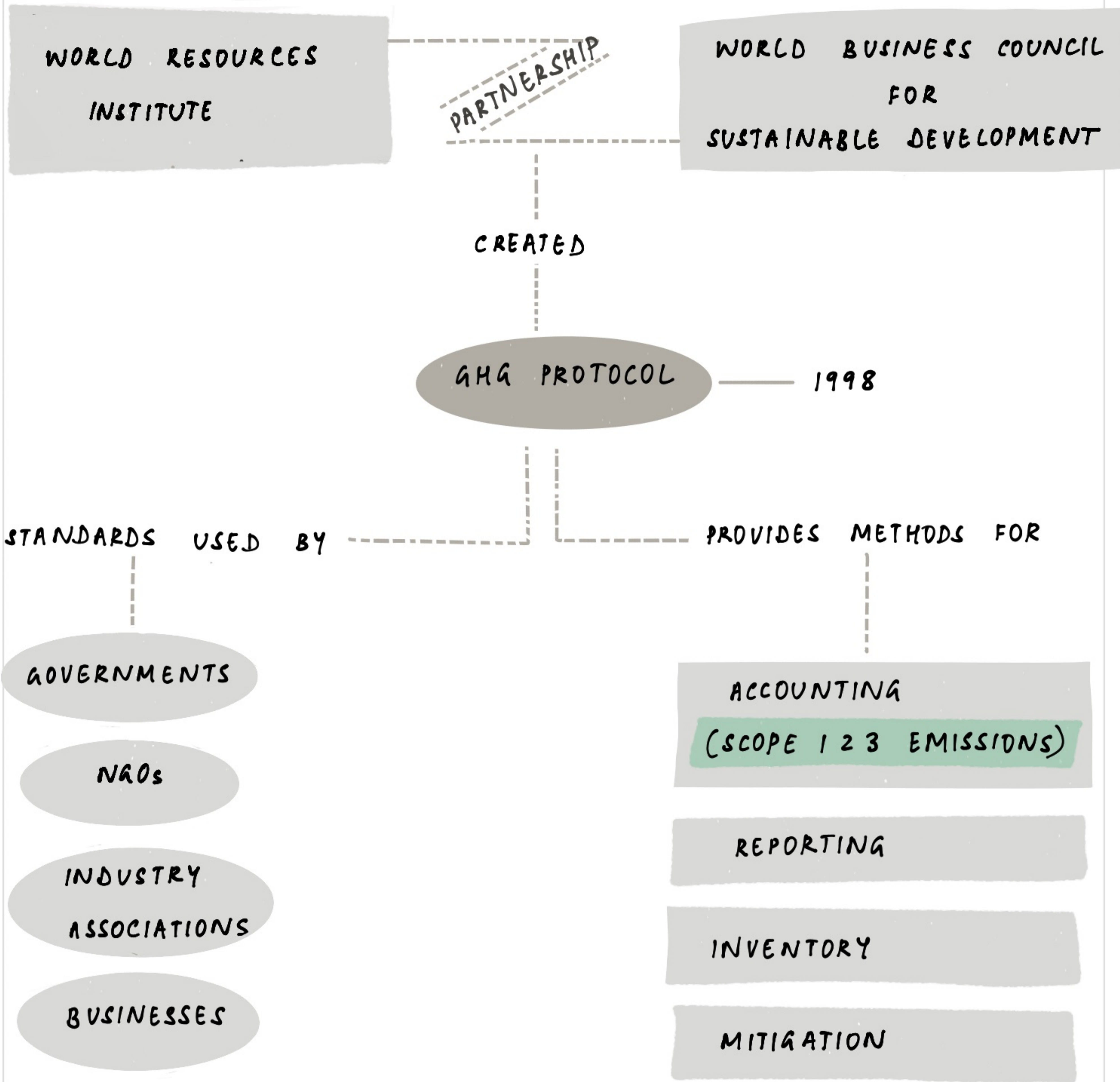
GHG PROTOCOL & ICT SECTOR

THE GHG PROTOCOL HAS THE FOLLOWING GUIDELINES

USE THE CORPORATE STANDARD TO CALCULATE SCOPE 123 EMISSIONS	USE THE PRODUCT STANDARD TO ESTIMATE LIFECYCLE EMISSIONS OF DEVICES

FOR SOFTWARE SERVICES EMISSIONS COME FROM

- DATA CENTRES
- NETWORKS
- USE/OPERATION
- OTHER IT INFRASTRUCTURE

THERE ARE SOME DIFFICULTIES IN QUANTIFYING EMISSIONS DUE TO THE NATURE OF THE ICT SECTOR SUCH AS

SOURCING MATERIALS/MINING

SHARED RESOURCES (CLOUD/ELECTRICITY)

SOLD PRODUCTS

END CUSTOMER USAGE

PRODUCT END OF LIFE

SOFTWARE CARBON INTENSITY

GREEN SOFTWARE FOUNDATION — — PART OF — — → LINUX FOUNDATION

HAS 4 WORKING GROUPS

OPEN SOURCE   STANDARDS   POLICY   COMMUNITY

SOON TO BE ISO STANDARD

SCI
SOFTWARE CARBON INTENSITY
SPECIFICATION

IS NOT CARBON FOOTPRINT

SCORES SOFTWARE BASED ON EMISSIONS
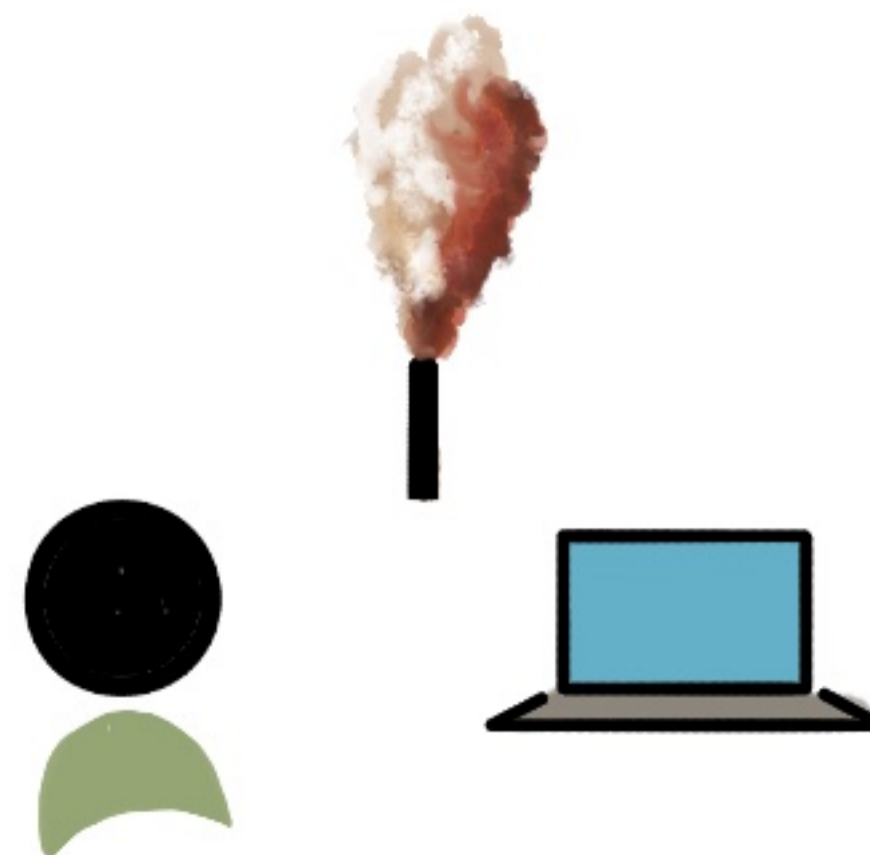
MEASURES EMISSIONS PER MINUTE OR PER DEVICE

TO CALCULATE SCI

$$SCI = ((E * I) + M) \quad PER \quad R$$

E → ENERGY CONSUMED IN KWH BY THE SOFTWARE

I → CARBON EMITTED PER KWH OF ENERGY gCO_2/KWH

M → CARBON EMITTED THROUGH HARDWARE

R → FUNCTIONAL UNIT OF HOW SOFTWARE SCALES
e.g. PER DEVICE   PER USER

ENABLES WIDER USE

R MAKES SCI VERSATILE IN USE.

CLOUD APPS, GAMES, IoT, WEBAPPS, OPEN SOURCE, DISTRIBUTED TEAMS

ENABLES COMPARISON

VERSIONS OF SOFTWARE
CAN BE COMPARED AS } → $CO_2/UNIT$

ENABLES REDUCTION

THE PARAMETERS ALLOW NO CONCESSIONS

THIS FORCES PEOPLE TO THINK OF DRIVING NUMBERS DOWN

TO REDUCE SOFTWARE EMISSIONS

GREEN SOFTWARE REALLY COMES DOWN TO

- **USING LESS PHYSICAL RESOURCES** → **HARWARE EFFICIENCY**
- **USING LESS ENERGY** → **ENERGY EFFICIENCY**
- **USING ENERGY INTELLIGENTLY** → **BASED ON ENERGY SOURCES/ AVAILABILITY**

HARWARE EFFICIENCY + ENERGY EFFICIENCY → **CARBON EFFICIENCY**

BASED ON ENERGY SOURCES/ AVAILABILITY → **CARBON AWARENESS**

CARBON EFFICIENCY + CARBON AWARENESS → **RESOURCE OPTIMISATION**

⑥ CLIMATE COMMITMENTS

UNDERSTAND CARBON REDUCTION METHODS

ORGANISATIONS TRY TO ACHIEVE EMISSION-RELATED GOALS
THEY DO SO IN ANY OF THE WAYS BELOW

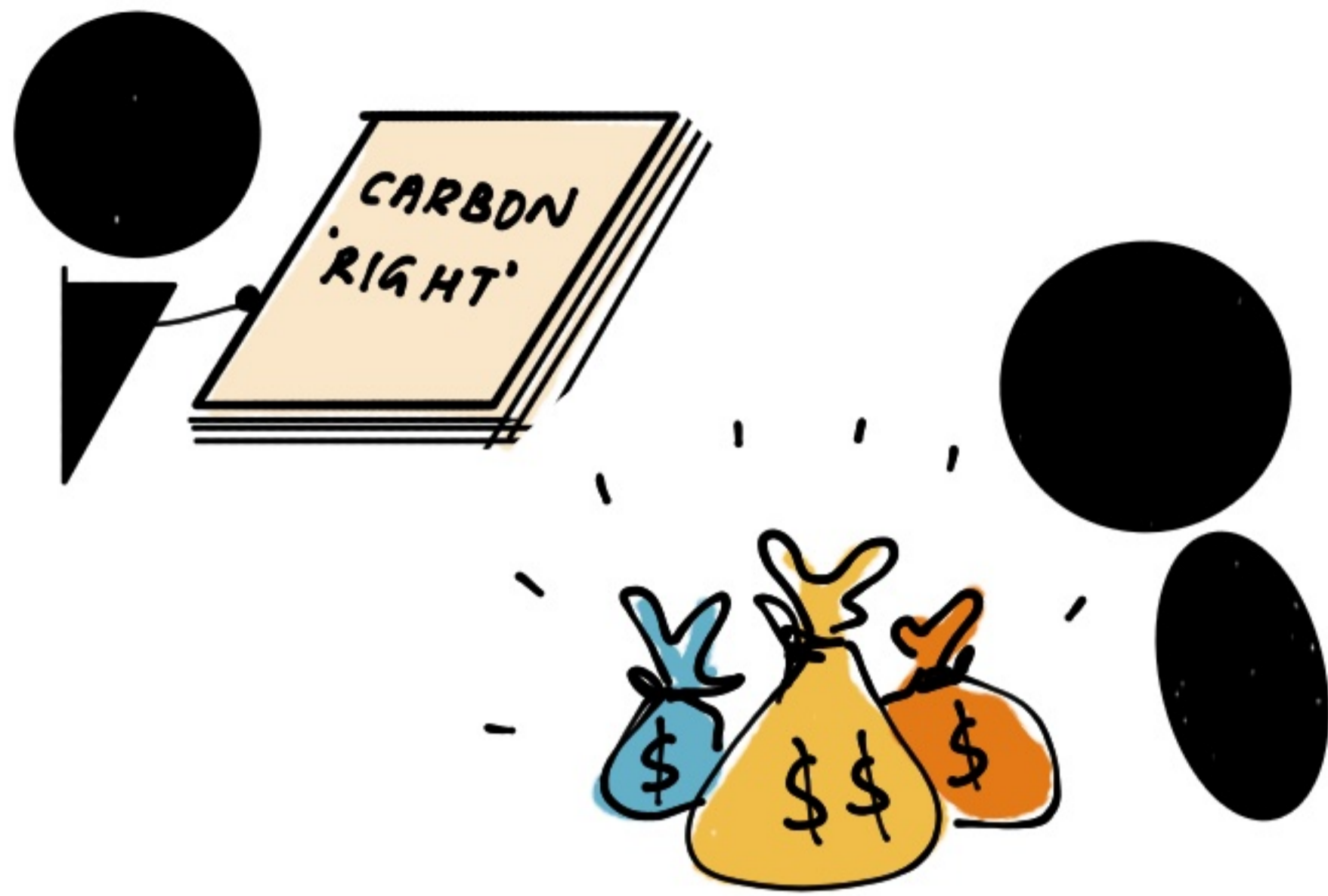REDUCING EMISSIONS

OFFSETS

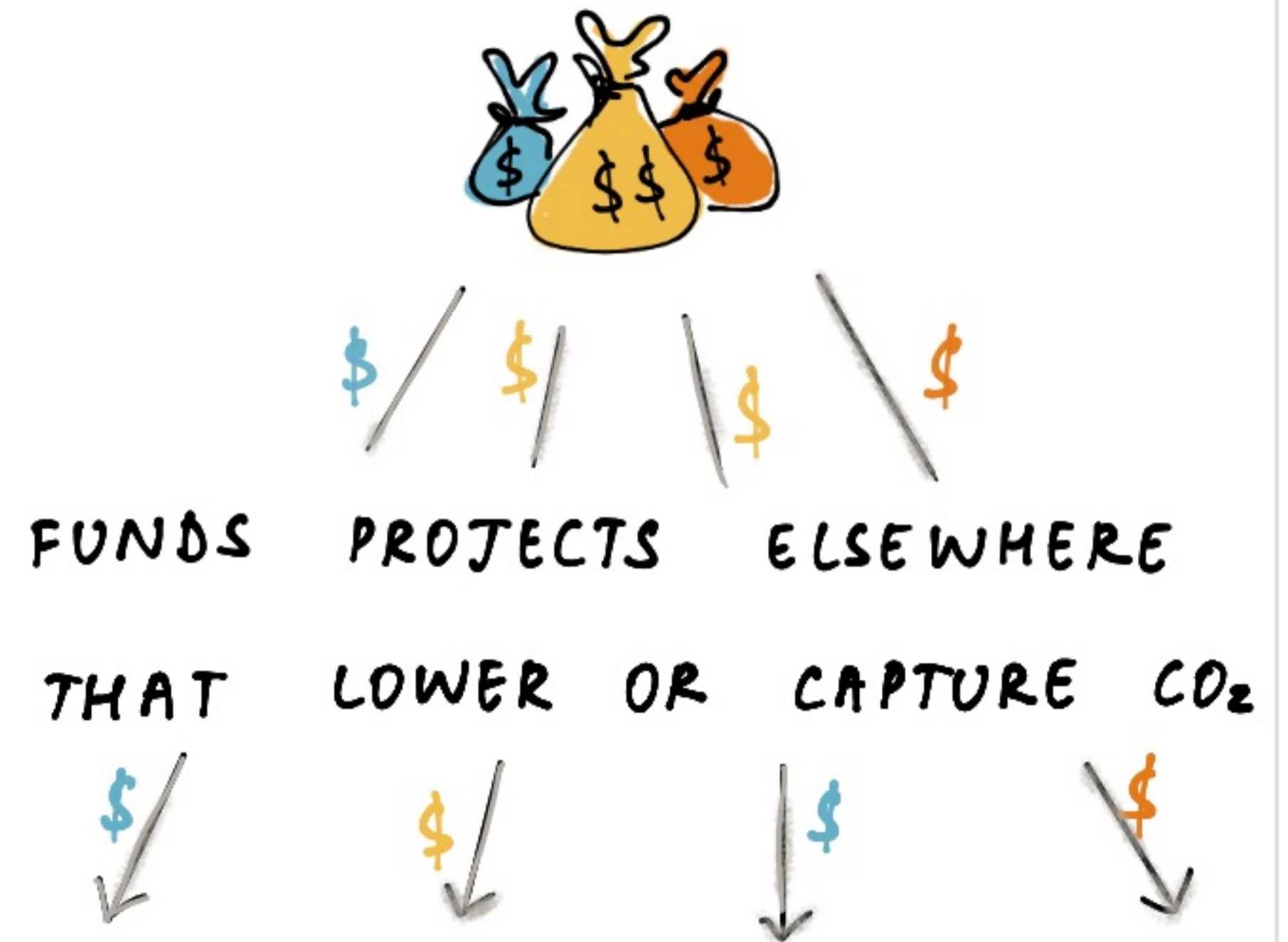ABATEMENT/ ELIMINATION

COMPENSATION/ AVOIDANCE

NEUTRALISATION REMOVAL

CARBON OFFSETS/CREDITS

A TRADEABLE CERTIFICATE

CARBON 'RIGHT'

OFFSETS EMISSIONS

FUNDS PROJECTS ELSEWHERE
THAT LOWER OR CAPTURE CO_2

OWN EMISSIONS UNCHANGED

CARBON 'RIGHT'

NO INCENTIVE TO
REDUCE EMISSIONS

PROJECTS BENEFIT

- SELLING OFFSETS FINANCES
PROJECTS LIKE

  - 🔵 REFORESTRATION
  - 🟡 RENEWABLES
  - 🟠 MANAGING WASTE

- SERVES AS A GREEN TAX

PROJECT LOCATIONS
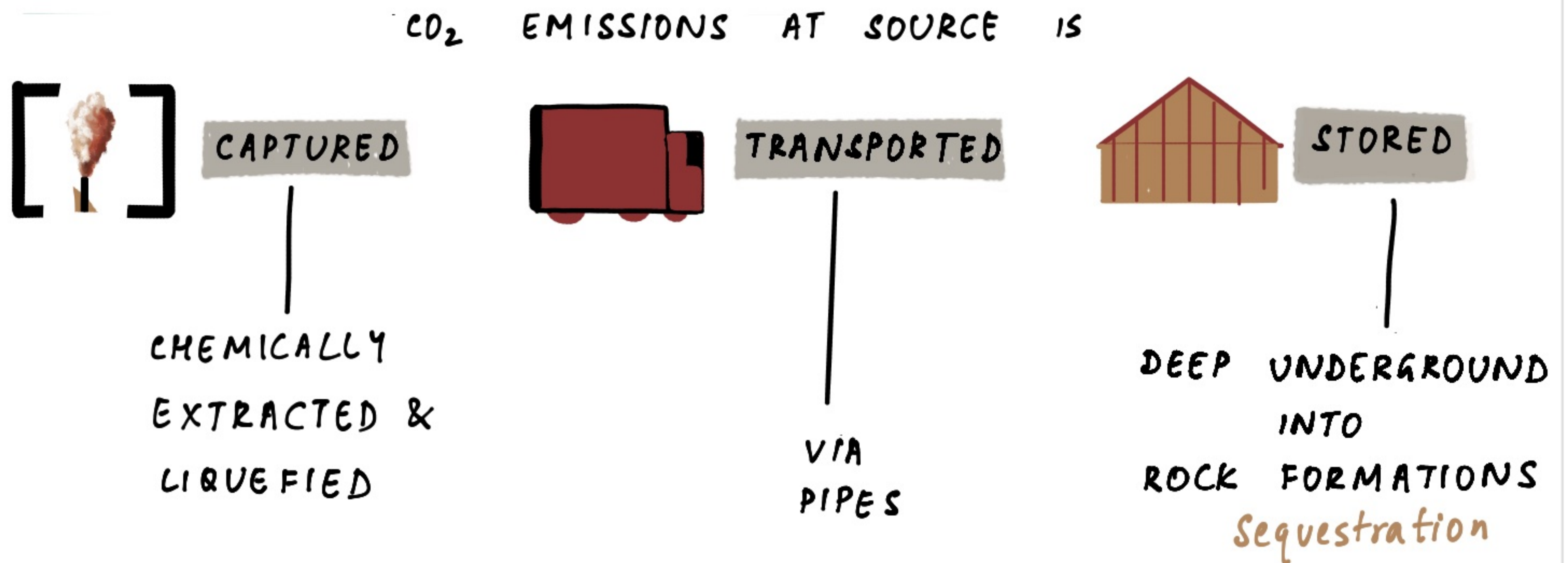
IN INDUSTRIES/AREAS*
WITH LOWER GHG
REDUCTION COSTS

* POORER COUNTRIES

WHY IT IS DUBIOUS

- 🟠 CHEAP TO BUY CARBON
- 🔵 HARD TO PROVE REDUCTION
- 🟡 ALLOWS THE RICH TO EMIT
- ⚫ EXPLOITS NATIVE LANDS

ABATEMENT/ELIMINATION

CARBON CAPTURE/STORAGE - CCS

CO_2 EMISSIONS AT SOURCE IS

CAPTURED

CHEMICALLY EXTRACTED & LIQUEFIED

TRANSPORTED

VIA PIPES

STORED

DEEP UNDERGROUND INTO ROCK FORMATIONS
Sequestration

CARBON CAPTURE/UTILISATION

THIS INVOLVES TURNING CAPTURED CARBON INTO

- FUEL
- CEMENT COMPONENTS
- PLASTICS

CARBON DIOXIDE REMOVAL - CDR

REMOVING CO_2 FROM THE AIR USING

FORESTS/CCS

PLANTING TREES
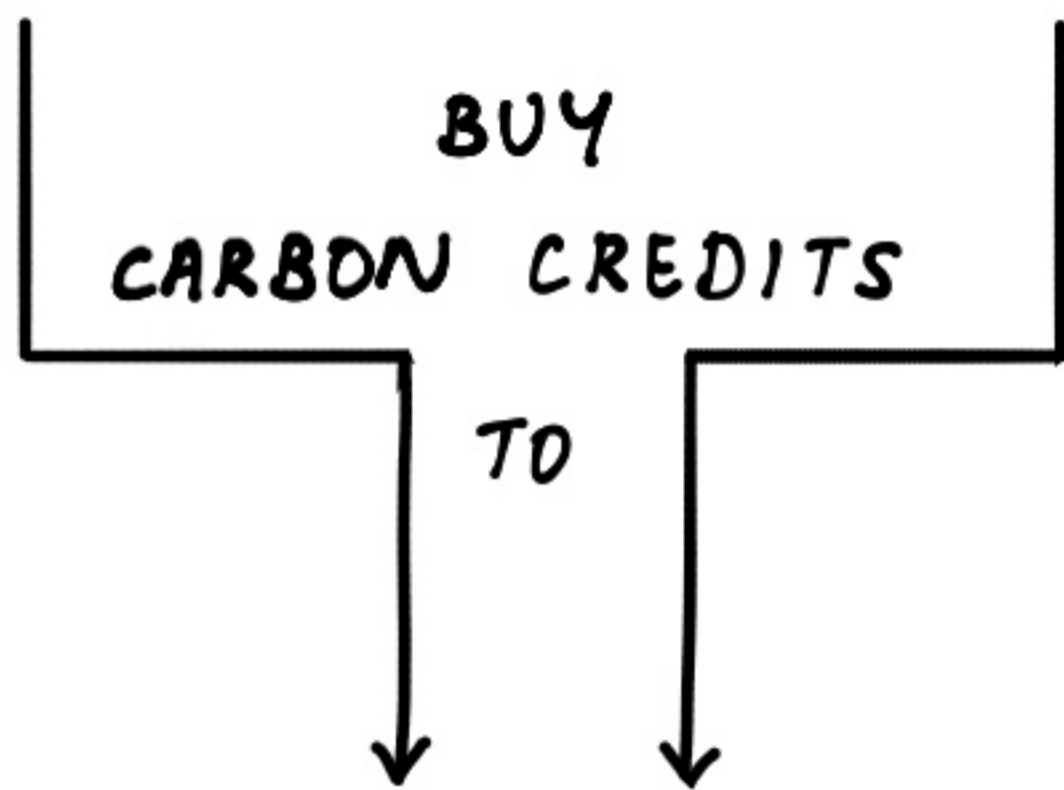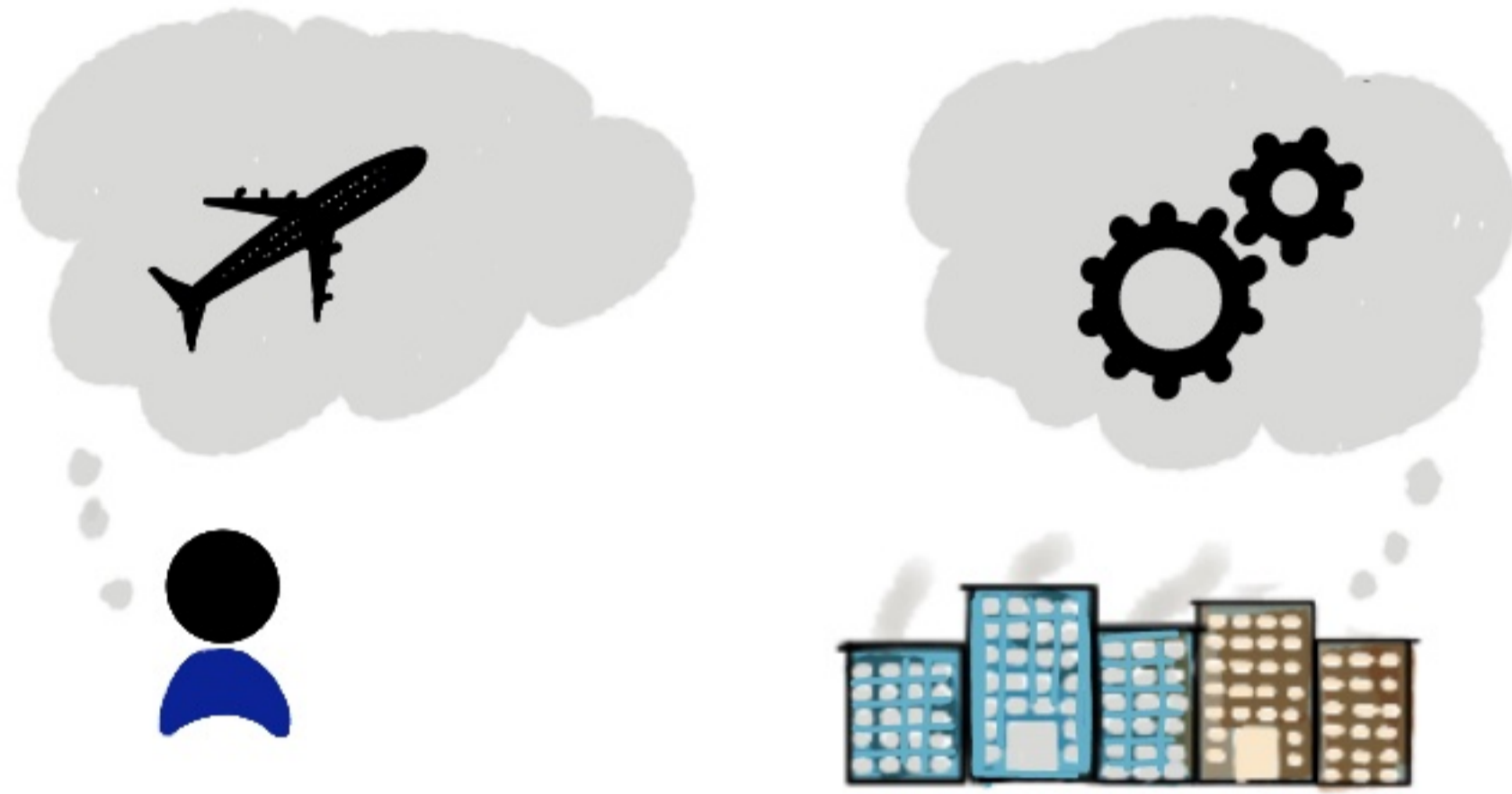ENGINEERED WOOD

OCEAN

USING ALGAE

TECHNOLOGICAL

MIMIC NATURAL PROCESSES

THERE IS APPARENTLY TECHNOLOGY + EQUIPMENT TO DO THIS
WE WOULD DO WELL TO EXERCISE CAUTION HERE, AS DESPITE
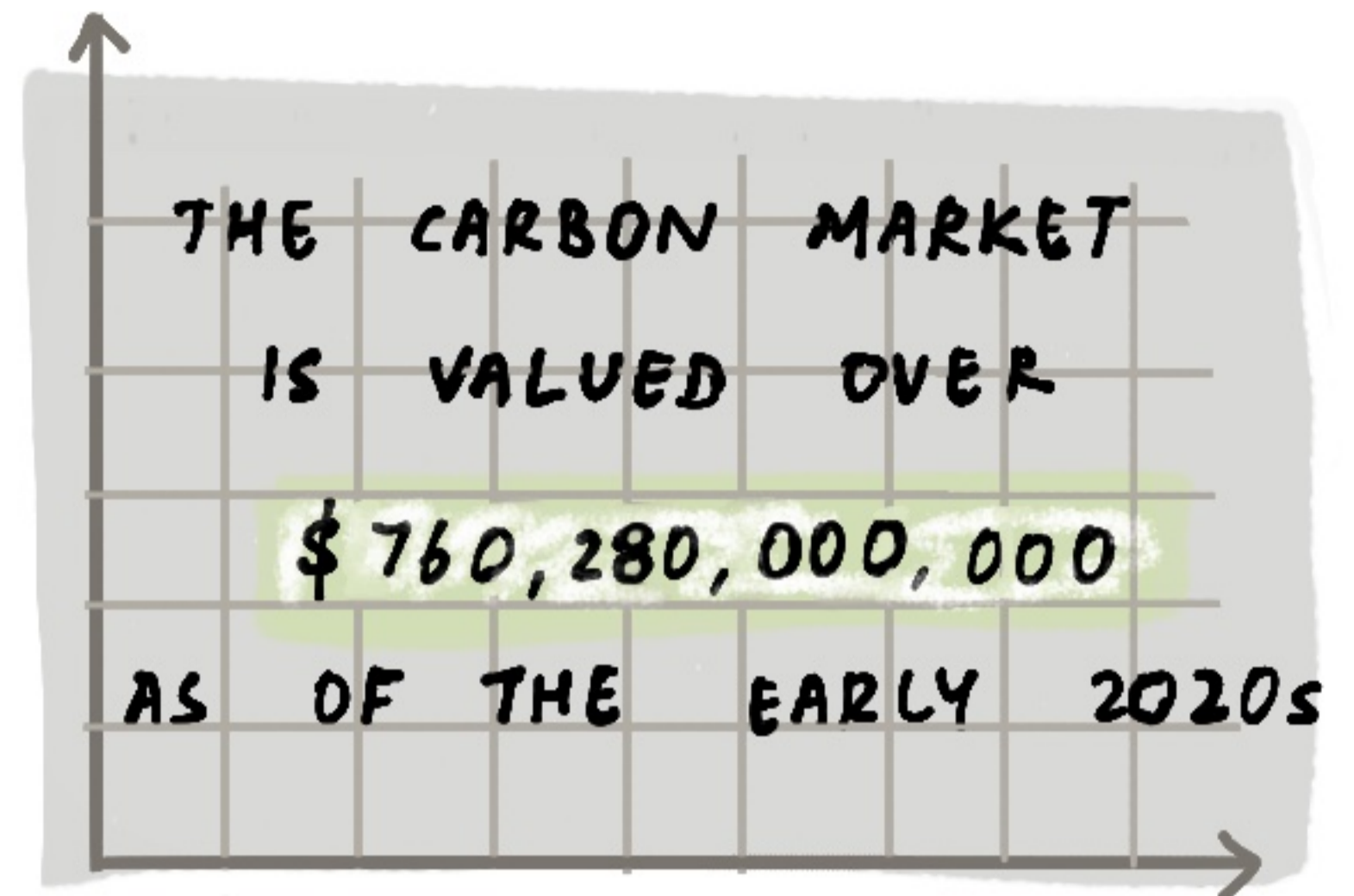CLAIMS, THE LONG TERM CONSEQUENCES/BENEFITS ARE HAZY

CARBON MARKETS

THE PLACE WHERE PEOPLE AND ORGANISATIONS
BUY AND SELL CARBON CREDITS

BUY
CARBON CREDITS
TO

- COMPENSATE FOR THEIR ACTIONS
- COMPLY WITH LAW

THE CARBON MARKET IS VALUED OVER
$760,280,000,000
AS OF THE EARLY 2020s

EACH CREDIT ALLOWS THE OWNER TO CONTINUE TO EMIT **ONE TON** OF CO_2 only FOR ^ UNDER **$80**

THE CREDIT IS A PERMIT TO POLLUTE

PRO ?

CARBON FINANCING UNDERLINES COMMITMENT BY COUNTRIES TO REDUCE CARBON EMISSIONS.

CON ?

OFFSETS MAKE COUNTRIES LOSE SIGHT OF ACTUAL REDUCTIONS OR EFFICIENCIES

CARBON REDUCTION

REDUCING EMISSIONS

- INVESTING IN LOW-CARBON ENERGY
  - WIND
  - SOLAR
  - HYDROGEN
  - NUCLEAR
- INCREASING EFFICIENCY
  - PROCESS
  - ENERGY — EFFICIENCIES
  - RESOURCE
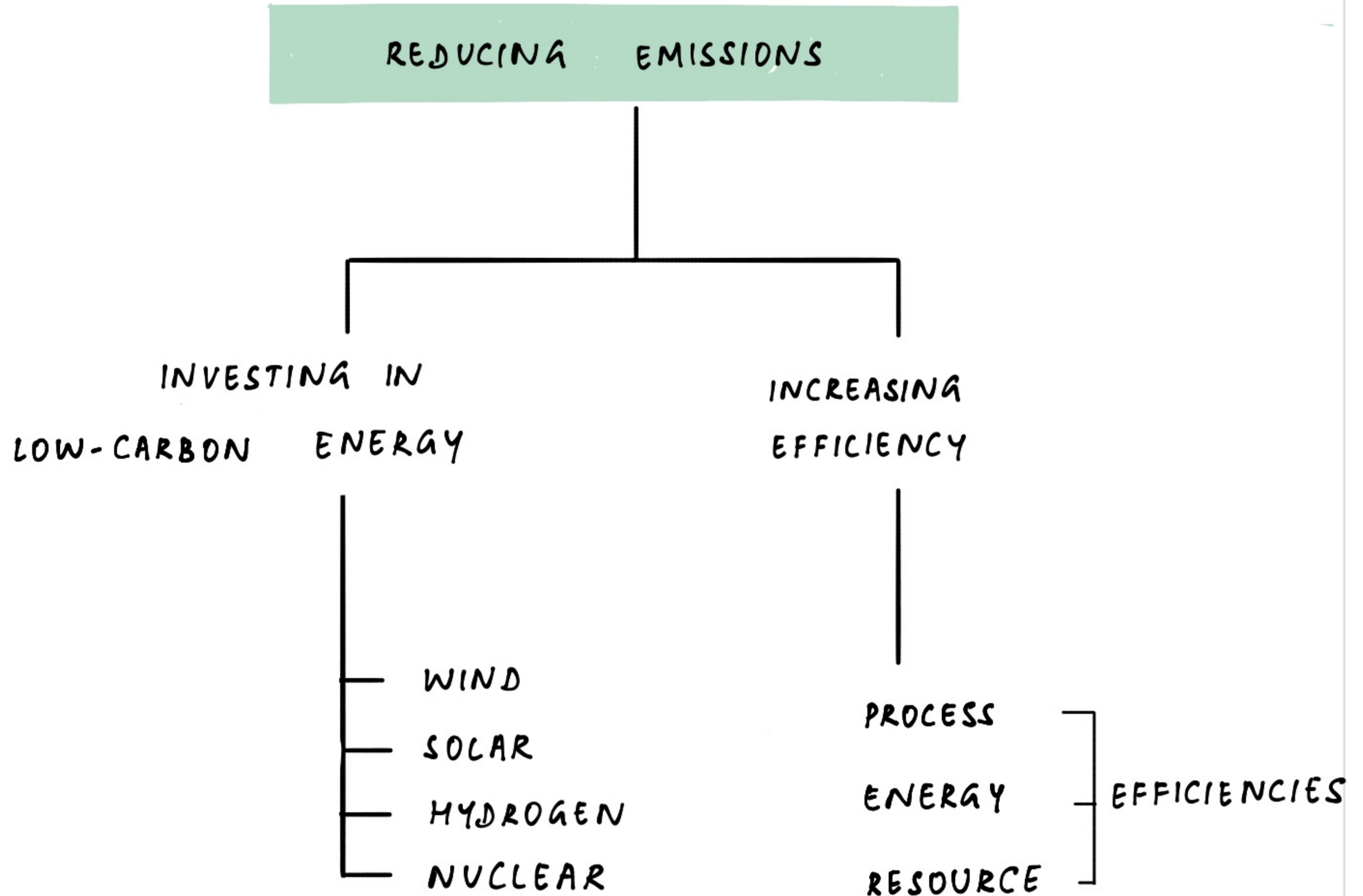
WHILE THIS APPEARS STRAIGHTFORWARD, THERE ARE ALSO MANY NUANCES TO GO INTO THAT ARE BEYOND THE SCOPE OF THIS BOOK.

HOW ARE GOALS SET?

ESG — SET OF STANDARDS MEASURING A BUSINESS ON ITS ACCOUNTABILITY TO THE WORLD AROUND

UNFORTUNATELY ESG HAS BEEN ACCUSED OF BEING "WOKE" CAPITALISM AND SIMPLY GREENWASHING

SBTi - SCIENCE BASED TARGETS INITIATIVE
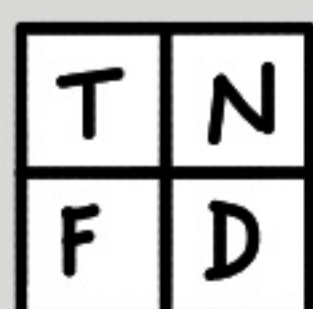
SBTi SETS REDUCTION TARGETS FOR PRIVATE SECTOR

CDP

UNITED NATIONS GLOBAL COMPACT

WORLD RESOURCES INSTITUTE

WWF

WE MEAN BUSINESS COALITION

TNFD - TASKFORCE ON NATURE-RELATED FINANCIAL DISCLOSURES

TNFD DISCLOSURE RECOMMENDATIONS & GUIDANCE TO REPORT AND ACT ON DEPENDENCIES, IMPACT, RISKS & OPPORTUNITIES

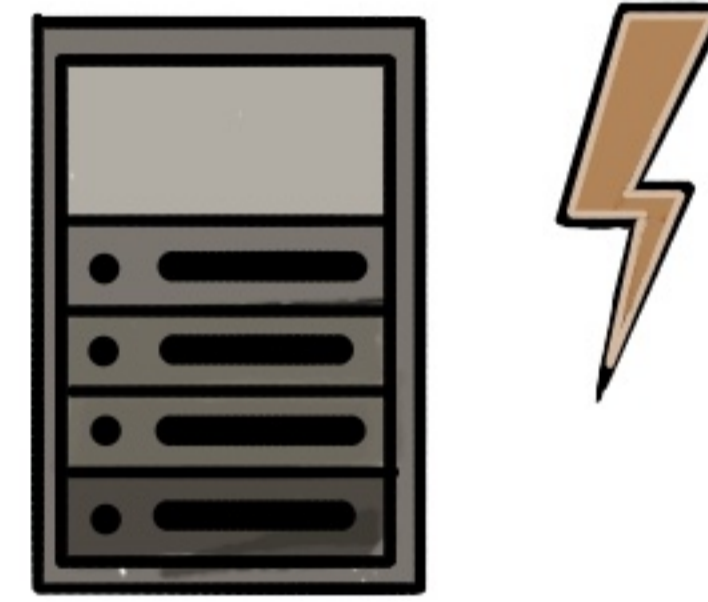SUPPORTED BY NATIONAL GOVERNMENTS, BUSINESSES & FINANCIAL INSTITUTIONS

GREENING OF IT

WHEN YOU WANT GREENER SOFTWARE

HARDWARE MATTERS TOO!

```
# Example code
def add (numbers):
    for num in numbers
        a + b
    return sum
```
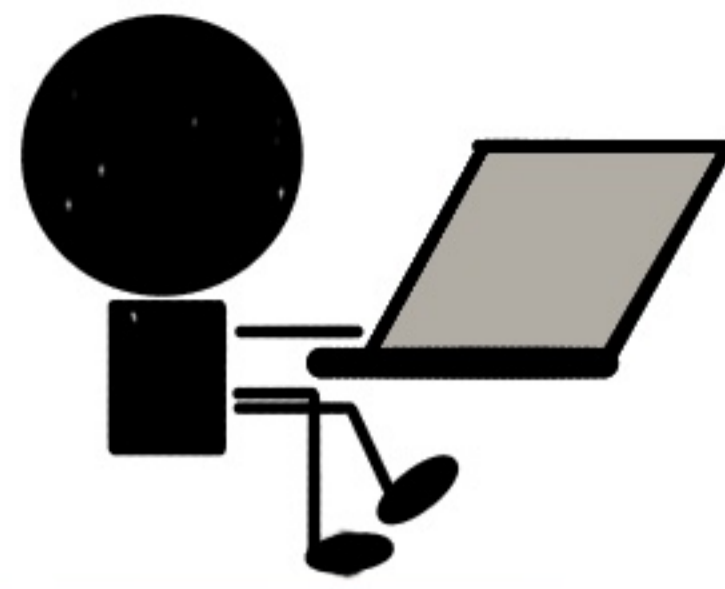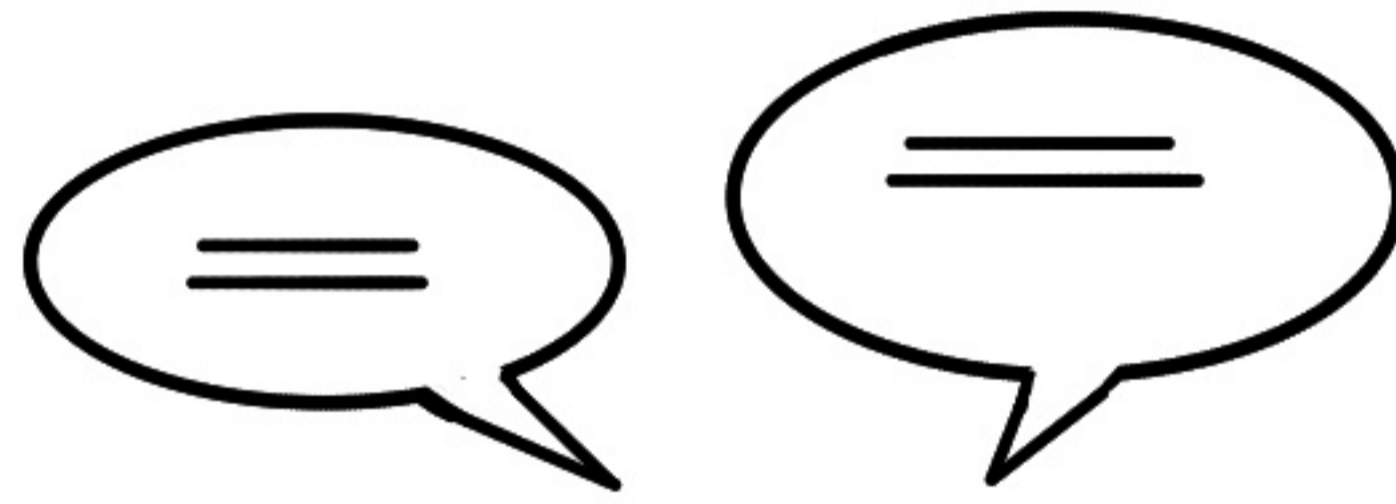
INEFFICIENTLY WRITTEN
SOFTWARE

IMPACTS →

HARDWARE LIFESPAN
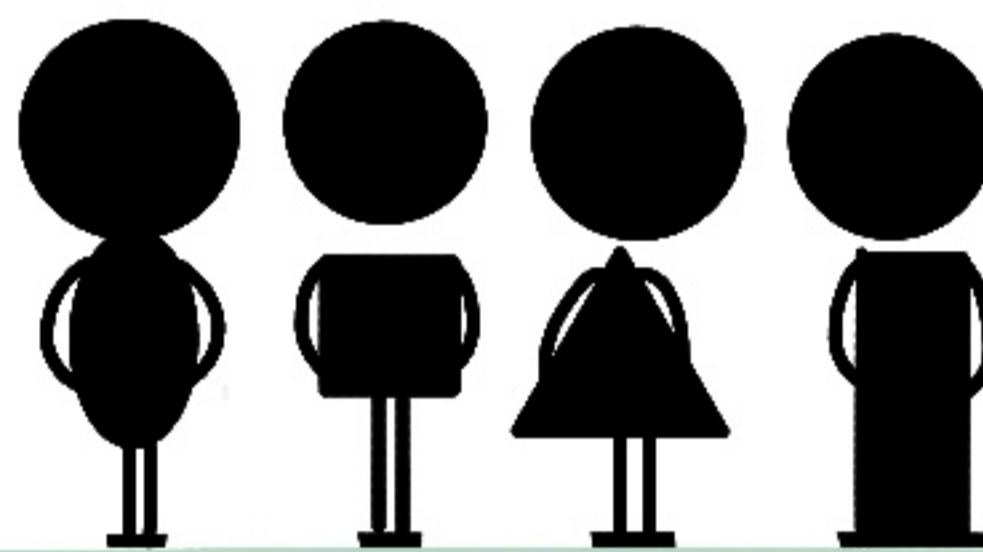ENERGY CONSUMPTION
PERFORMANCE

AREAS OF FOCUS

DESIGN AND CODING
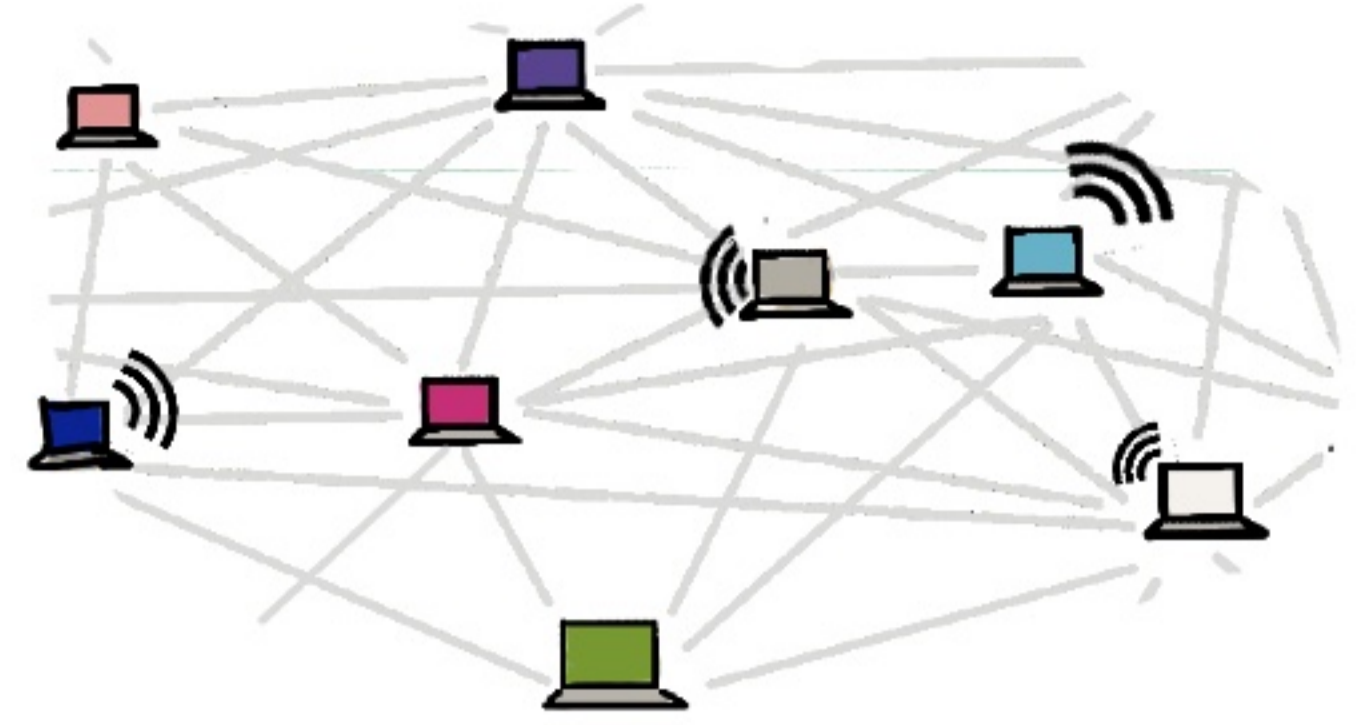
CHOICE OF LANGUAGE

SELECTION OF AI MODELS

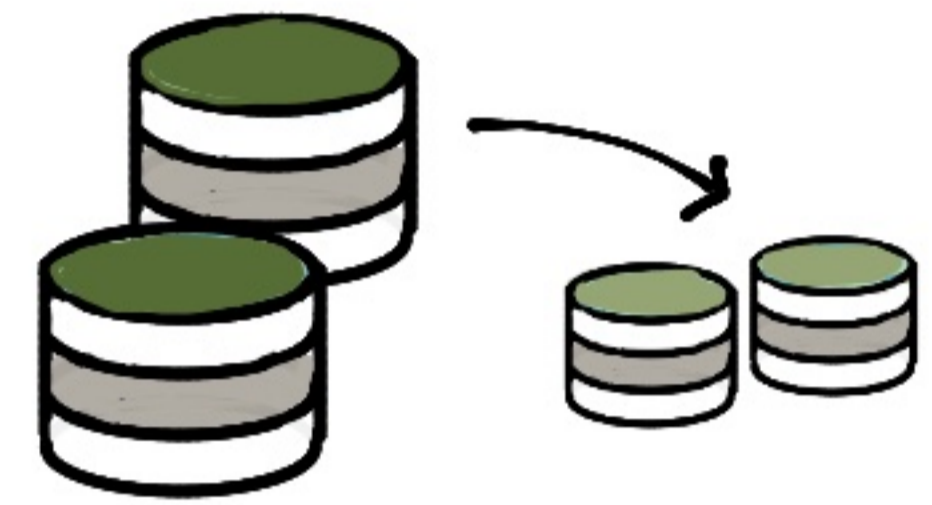DATA CENTRES

DESIGN AND CODING

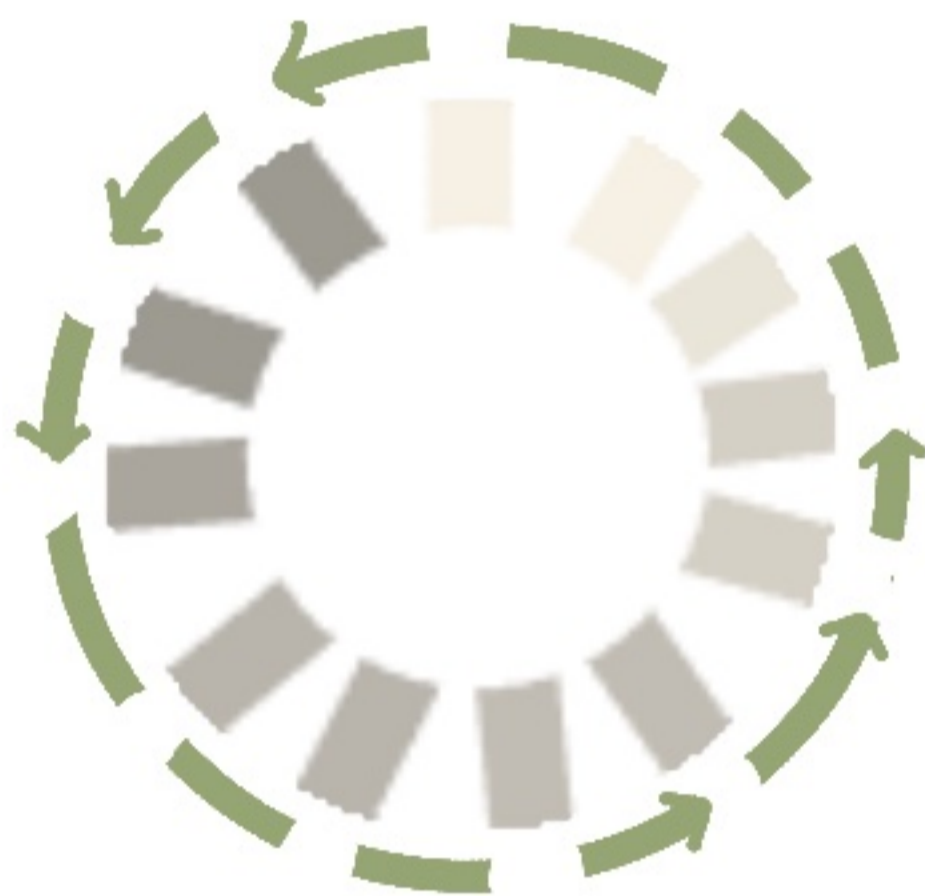UNDERSTAND GREEN
SOFTWARE PATTERNS

MAKE FEWER NETWORK CALLS

MONITOR ENERGY
CONSUMED

REDUCE DATA USAGE

CONTROL UPDATES TO
KEEP HARDWARE
COMPATIBLE

ENABLE ECO MODE,
POWER SAVE MODE
FEATURES
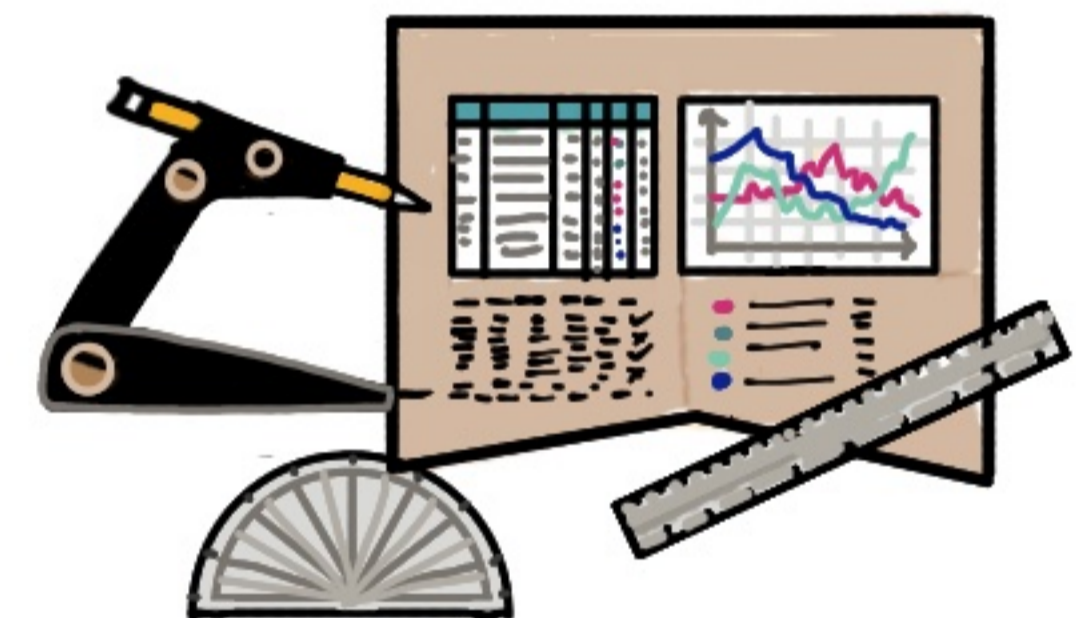
GET PROFILER DATA
ON RESOURCES CONSUMED
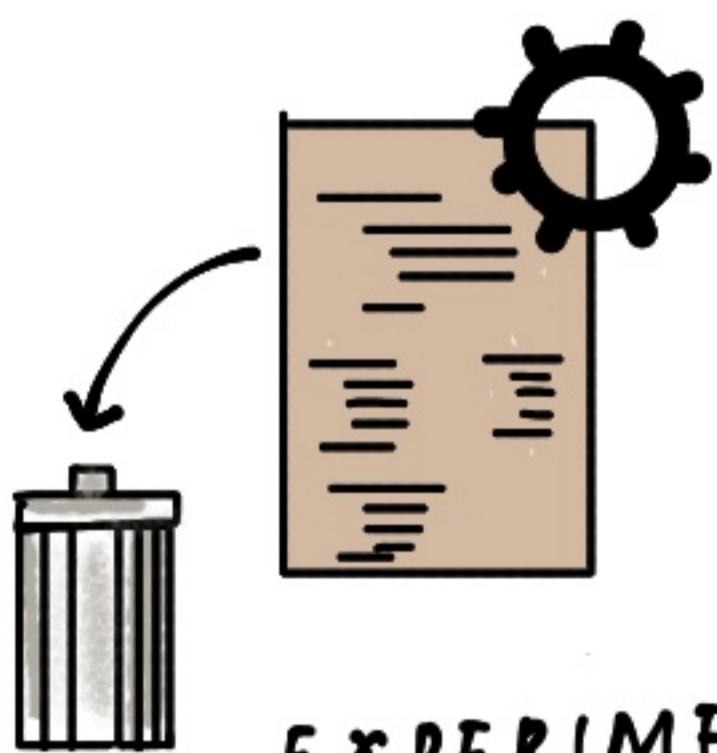
EXPERIMENT!
- SOME TRIAL & ERROR

USE THE LEARNINGS AS

SENSIBLE
DEFAULTS

CHOICE OF LANGUAGE

ENERGY EFFICIENCY ACROSS PROGRAMMING LANGUAGES – 2017

HOW DO ENERGY, TIME AND MEMORY RELATE?

AUTHORS

RUI PEREIRA   RUI RUA

MARCO COUTO   JÁCOME CUNHA

FRANCISCO RIBEIRO   JOÃO PAULO FERNANDES

JOÃO SARAIVA

THE PAPER PRESENTS A STUDY OF 27 SOFTWARE LANGUAGES

VIRTUAL MACHINE

INTERPRETED

COMPILED

CONCURRENT

IMPERATIVE

OBJECT- ORIENTED

FUNCTIONAL

SCRIPTING

CHOICE OF LANGUAGE

HERE ARE SOME OBSERVATIONS IN THE PAPER:

COMPILED "TEND TO BE" BOTH EFFICIENT & FAST

THE LEAST MEMORY USED WERE LIKELY COMPILED

IN SOME CASES INTEPRETED CAME OUT MORE EFFICIENT

IMPERATIVE LANGUAGES CAME OUT TOP EFFICIENCY AMONG PROGRAMMING PARADIGMS

A FASTER LANGUAGE IS NOT ALWAYS MOST ENERGY-EFFICIENT

WHILE THERE WAS NO SINGLE 'GREENEST' LANGUAGE, THE FACTORS TO CONSIDER WHEN CHOOSING A LANGUAGE ARE

ENERGY

MEMORY

EXECUTION TIME

CONTEXT

CHOICE OF AI MODEL

IMPROVEMENTS IN AI/ML OFTEN COME WITH HIGH CARBON FOOTPRINTS
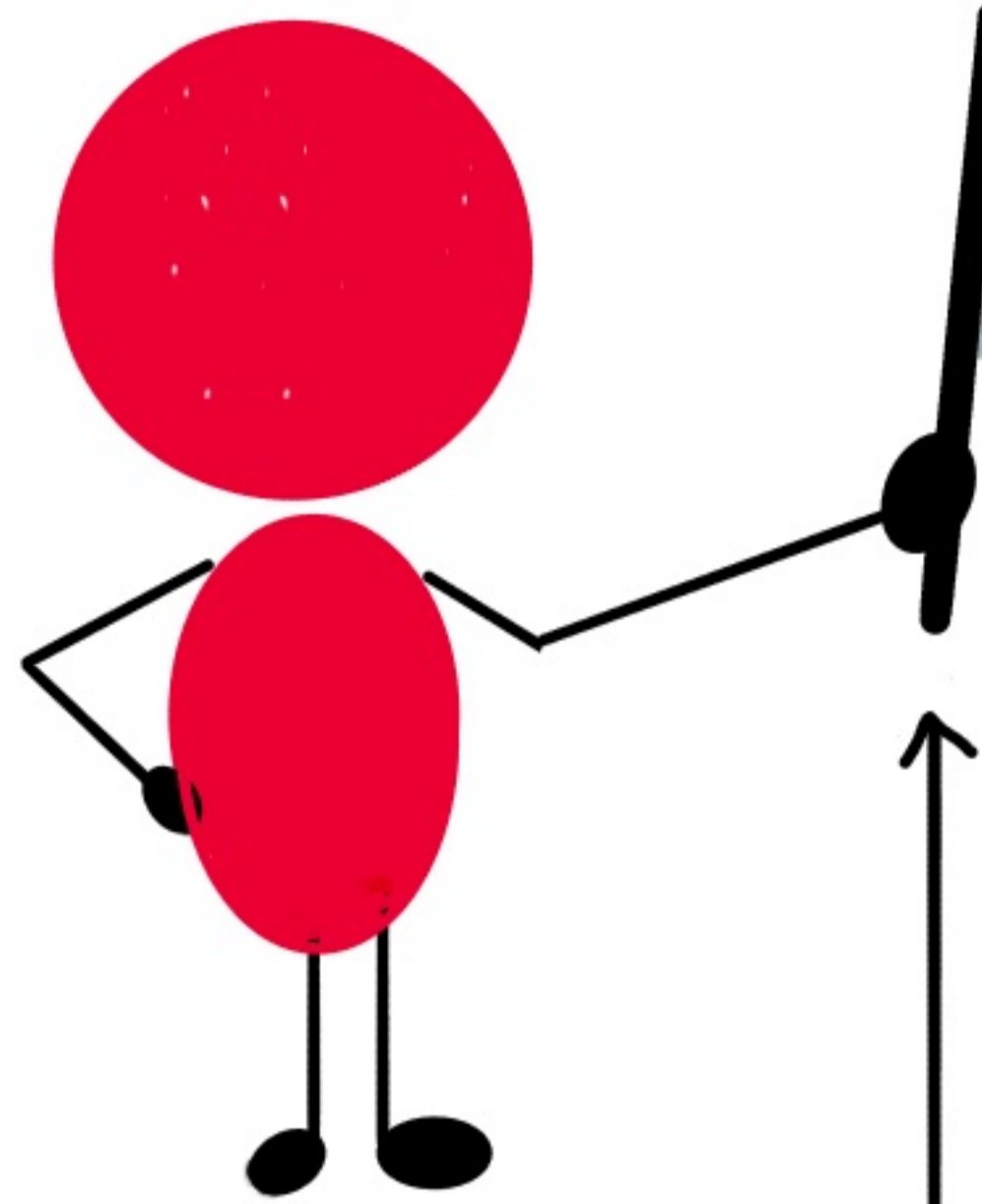
also act as barrier to entry for the smaller players because of HIGH COSTS

RED AI

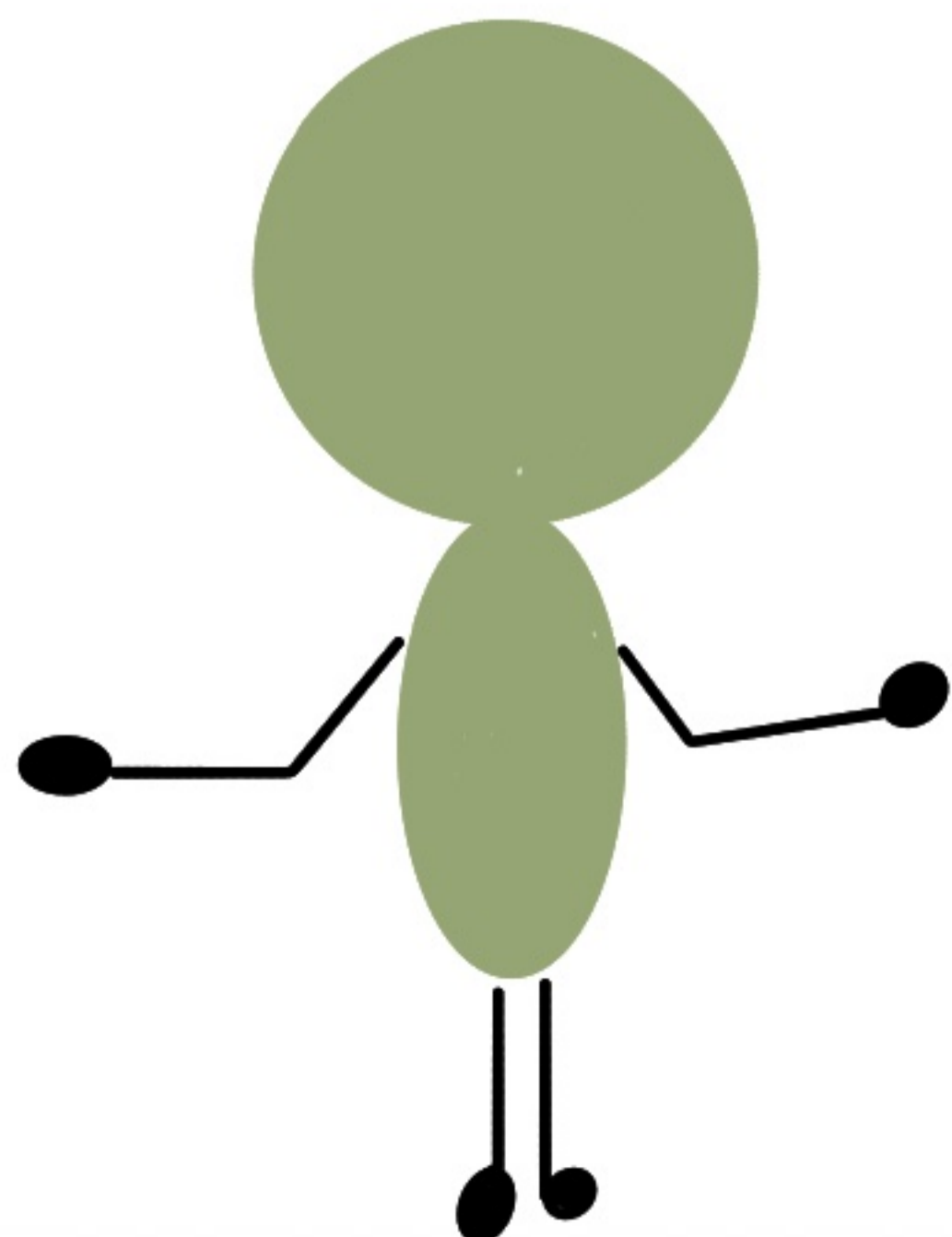EVEN THOUGH THE IMPROVEMENTS ARE VALUABLE, LIFE SAVING

LARGER AI MODELS → MORE CAPACITY → HIGHER ACCURACY → HIGH VALUE

obtained exploitatively?

POSSIBLY GENERATED WITH DATA ON A MASSIVE SCALE ONLY PROCESSED BY A FEW WITH LARGER INFRASTRUCTURE

HOW TO MOVE TO GREEN AI?

TOWARDS GREEN AI

PAY ATTENTION TO AI COMPUTATIONAL EFFICIENCY + ACCURACY AND MEASURE TRADE-OFFS OF PERFORMANCE V EFFICIENCY

— ACM.ORG

ARTICLE ON GREEN AI BY RORY SCHWARTZ NOAH SMITH
JESSE DODGE OREN ETZIONI

MEASURE
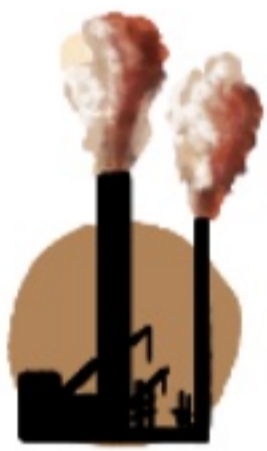
EMISSIONS
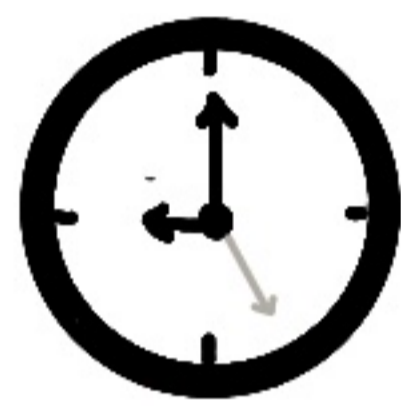
ELAPSED REAL TIME FOR RESULT

ELECTRICITY USAGE

NO. OF FLOATING POINT OPERATIONS

REPORT

BUDGET
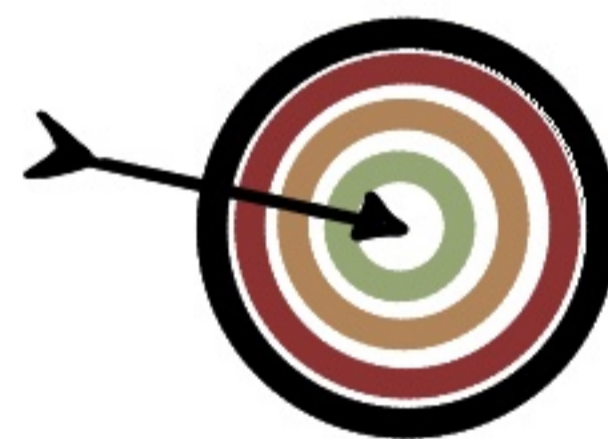
PERFORMANCE

MODEL SIZE

USE

✓ SMALLER MODELS

✓ STARTUPS/UNIVERSITIES AS PARTNERS

✓ EFFICIENT HARDWARE CONFIGS

✓ GREEN SOFTWARE FOUNDATION RESOURCES

DATA CENTRES

EVERY   DIGITAL   SERVICE

HAS   A   DATA   CENTRE   THAT   CAN

SEARCH   STORE   PROCESS   DISTRIBUTE
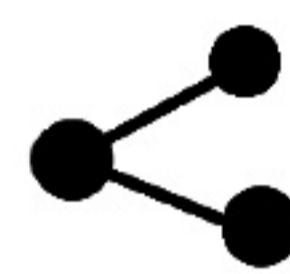
DATA | APPLICATIONS | RESOURCES

A MILLION GALLONS

THESE OPERATIONS CONSUME POWER & GENERATE HEAT

WATER THAT COOLS SERVERS

DRAINS LOCAL SUPPLY

POLLUTES RIVERS

CAUSES DISEASE

HOW TO ACHIEVE ENERGY EFFICIENCY?

HOW TO KEEP SERVERS COOL?

DATA CENTRES

IN THE VERY WORTHY QUEST TO MAKE DATA CENTRES GREEN MANY LEADING CLOUD PROVIDERS HAVE THEIR INDIVIDUAL PLEDGES

TOOLS FOR MEASURING EMISSIONS

90%
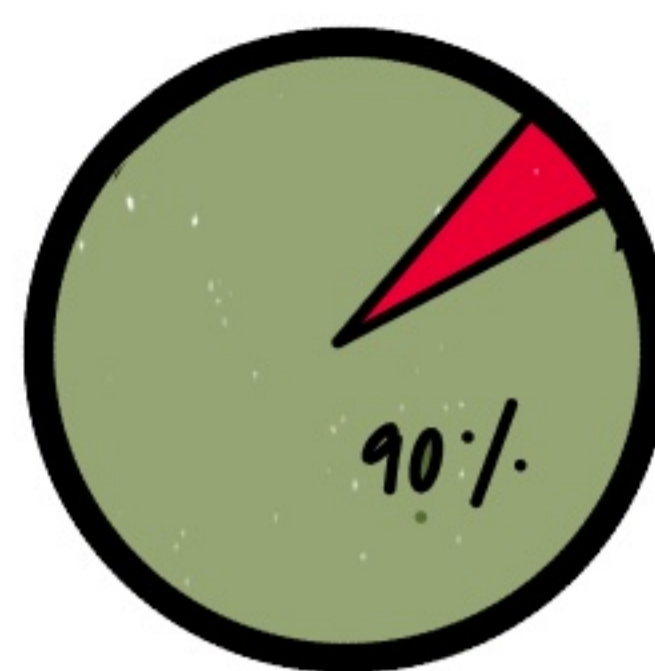
HIGHER SERVER UTILISATION
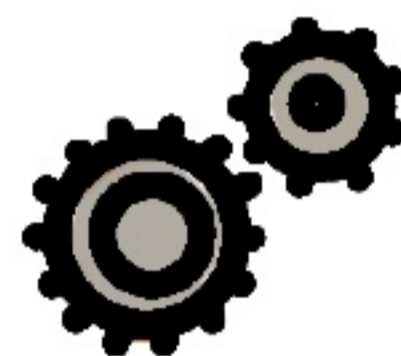
SHARED { NETWORKING POWER COOLING }
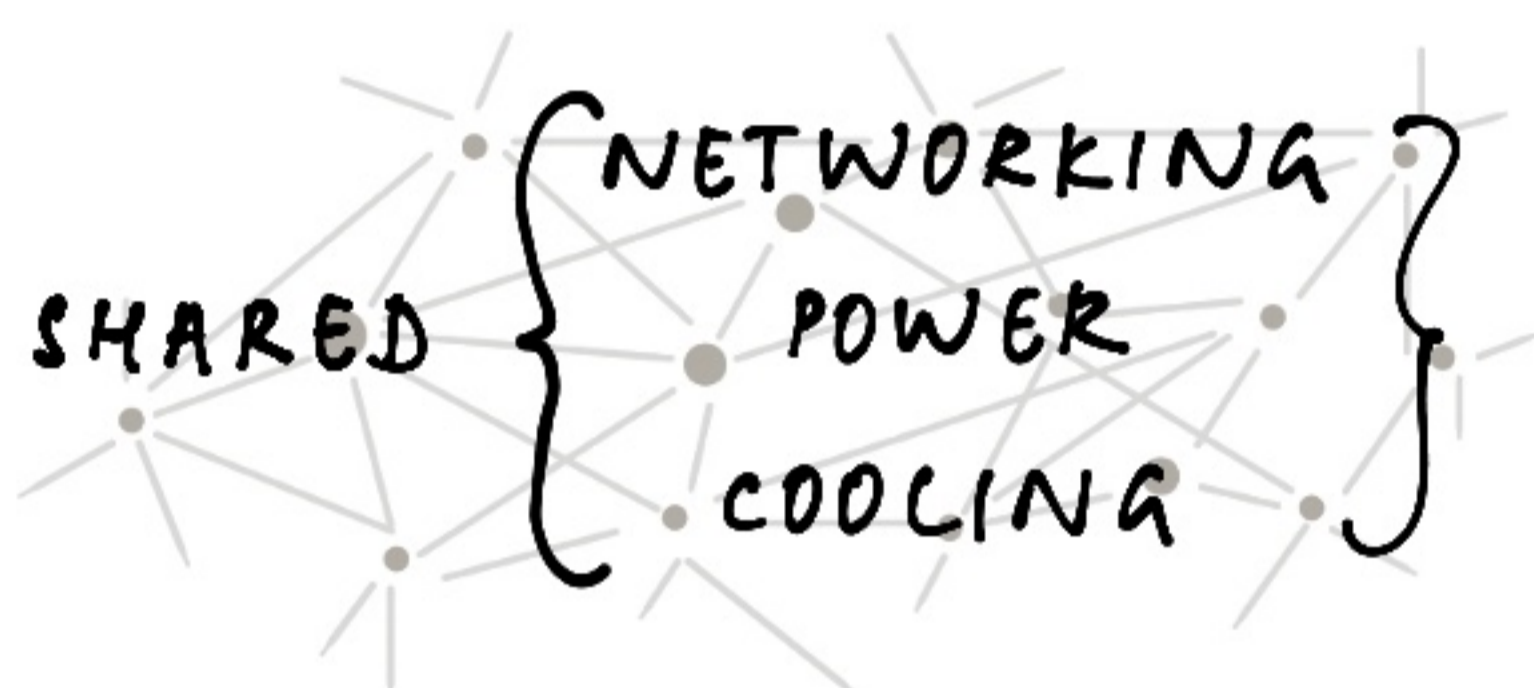
ENERGY [REDUCTION EFFICIENCY]

USING RENEWABLE ENERGY

$$\frac{TOTAL\ ENERGY}{ENERGY\ FOR\ COMPUTE}$$

COMPUTE

OVERHEAD e.g. cooling

IMPROVING PUE
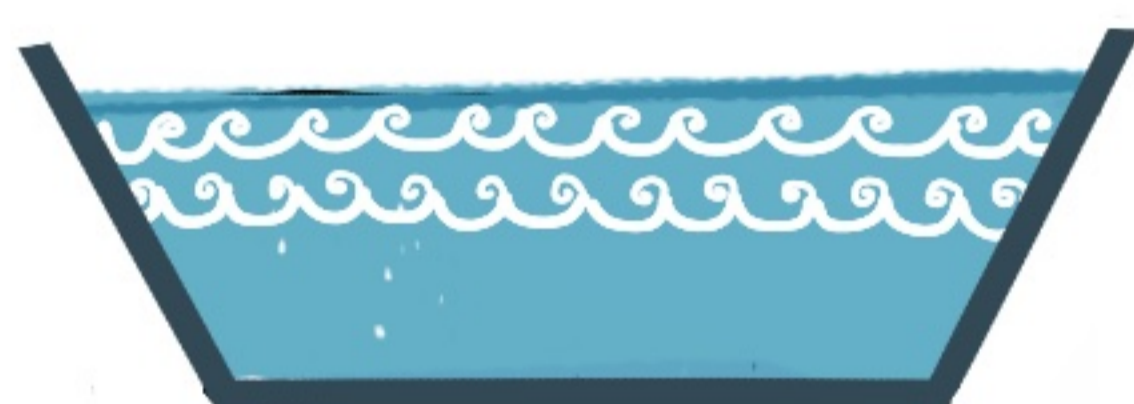
REPLENISH WATER

IMPROVE WATER QUALITY

BETTER COOLING TECHNOLOGY

REDUCE/ZERO WASTE AT LANDFILLS

BUILD PRODUCTS THAT HELP SUSTAINABILITY

GREENING BY IT

WHEN SOFTWARE HELPS YOU BECOME GREENER

GREENING BY IT

WHILE THE IT SECTOR IS PART OF THE PROBLEM, IT CAN ALSO BE USED AS PART OF THE SOLUTION.

ACCORDING TO GESI.ORG GLOBAL E-SUSTAINABILITY INITIATIVE, IT CAN BE AN ENABLER OF SUSTAINABLE CHOICES.

TECHNOLOGY ENABLED SOLUTIONS AIM TO

- REDUCE RESOURCE CONSUMPTION
- REDUCE EMISSIONS
- ENHANCE EFFICIENCIES
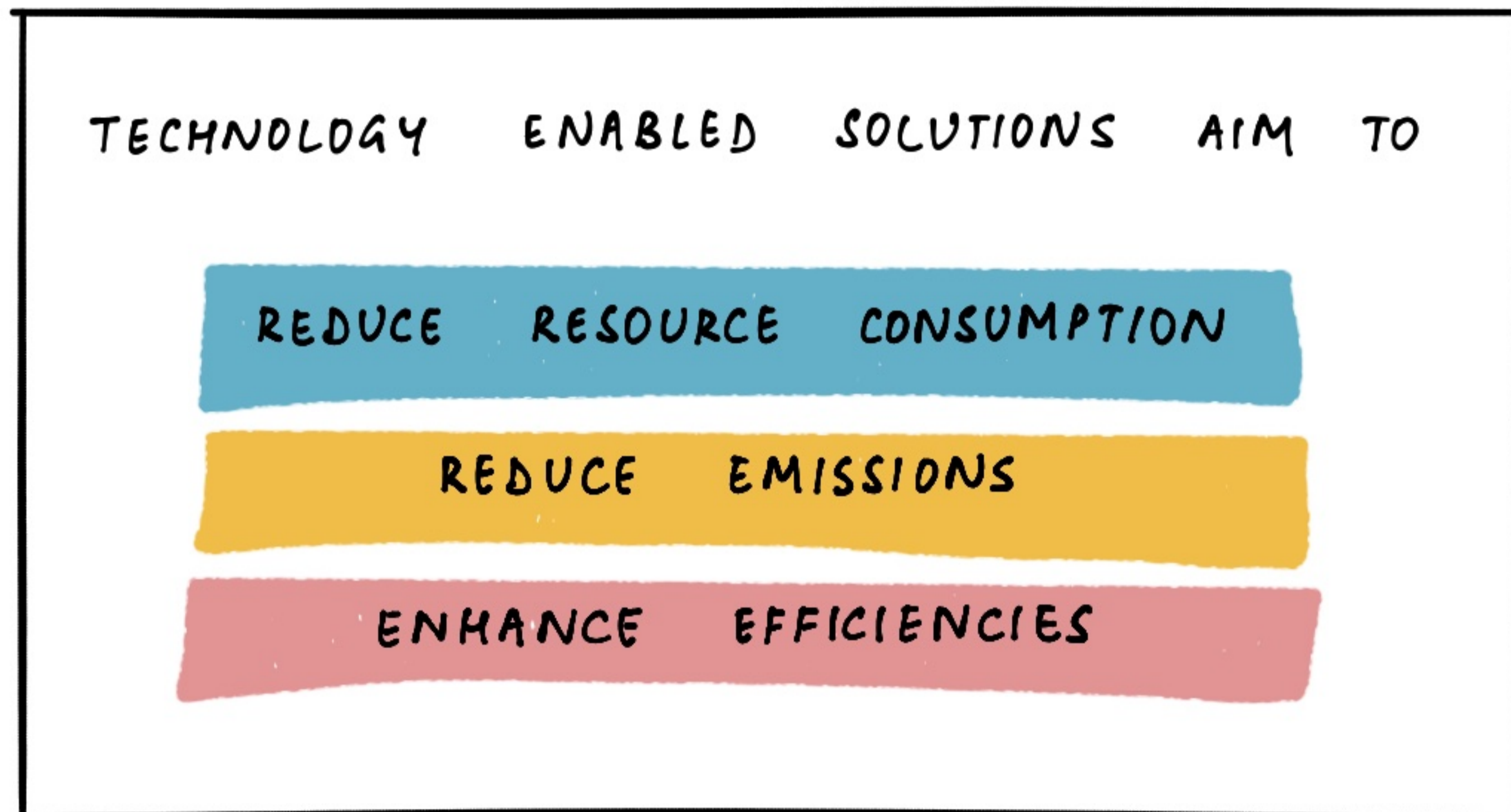
A QUICK INTERNET SEARCH SHOWS A WIDE RANGE OF PRODUCTS THAT SERVE MANY FUNCTIONS ACROSS DOMAINS

WE MUST ASSUME THAT THE BENEFITS OF USING THE TOOLS EXCEED THE COSTS OF BUILDING/OPERATING THEM

THUS, DISCUSSING THE MERITS OF EACH TOOL GO BEYOND THE SCOPE OF THIS BOOK

HOWEVER, WE CAN ROUGHLY CATEGORISE THE USE CASES

GREENING BY IT

THE TOOLS COULD PROVIDE ANY OF THE FUNCTIONS BELOW

UNDERSTANDING THE PRESENT - EXAMPLES

kWh

18 19 20 21 22 23 24
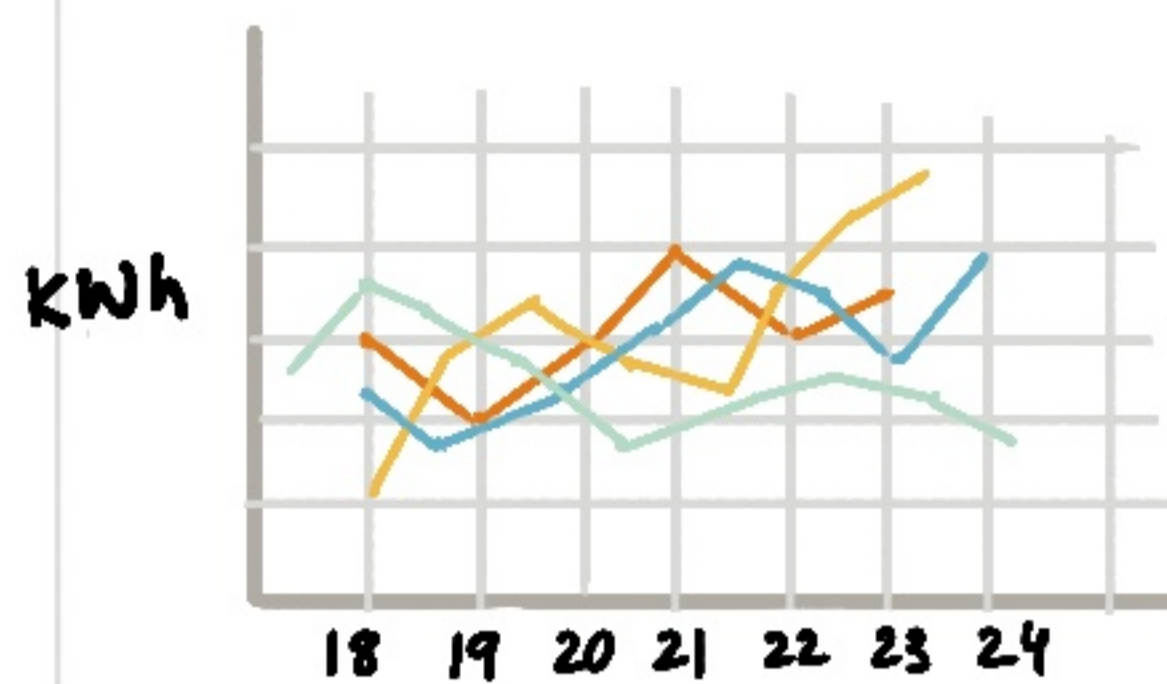
DASHBOARD OF ENERGY CONSUMED
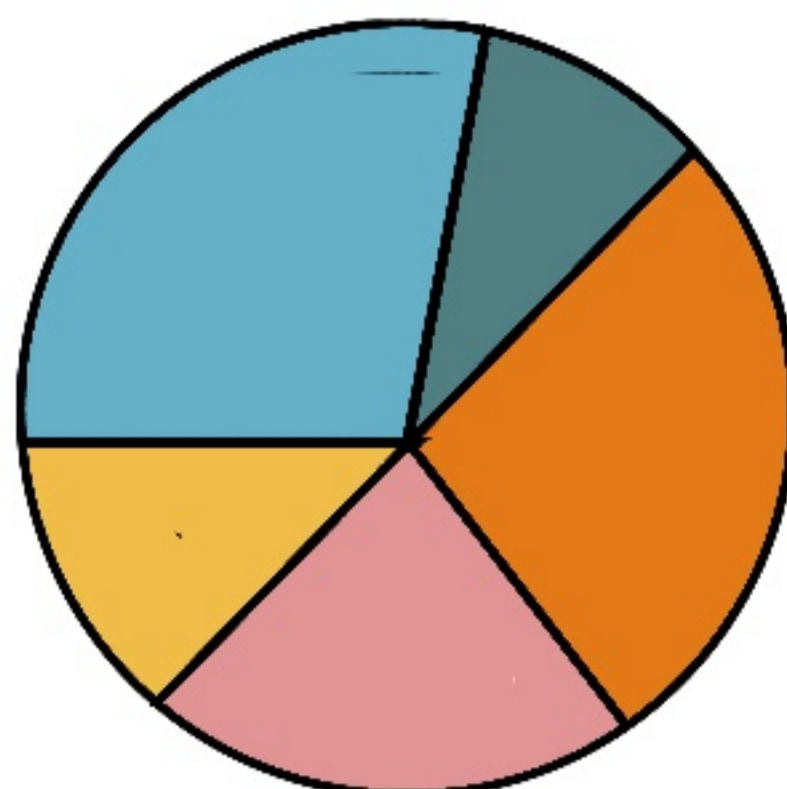
PRODUCT LIFECYCLE IMPACT ASSESSMENT

CLOUD FINANCIAL OPERATIONS

CARBON TRACKING TO MANAGE COSTS

OPTIONS FOR THE FUTURE - EXAMPLES

80%
5%

INSIGHTS

BUY
EXTEND
REDUCE
SHIFT
SHUT
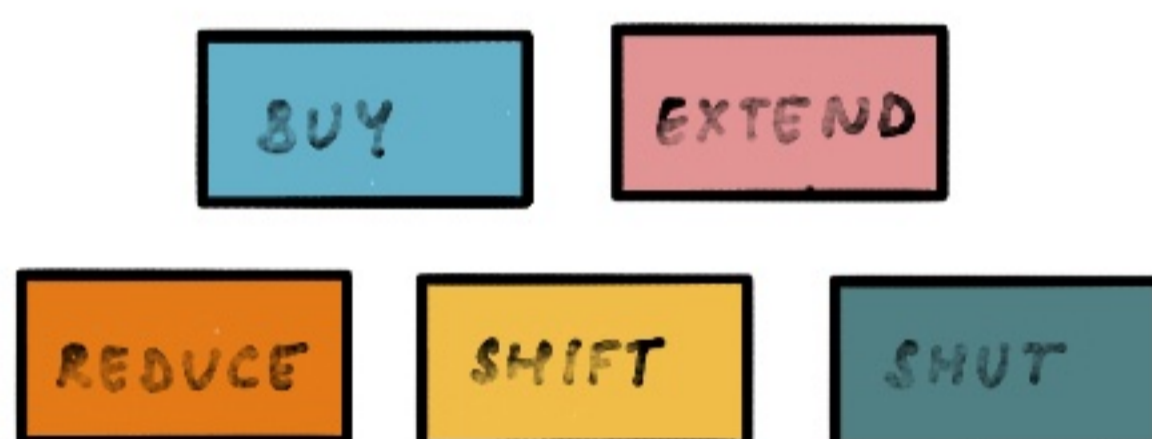
RECOMMENDATIONS
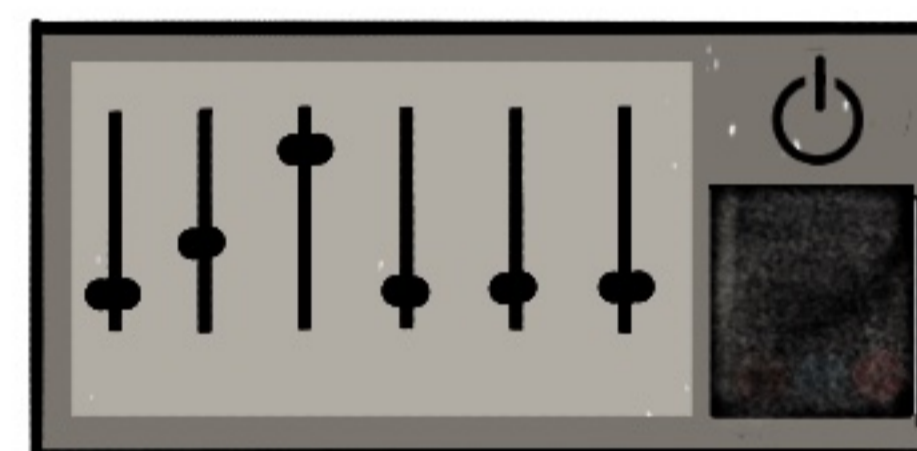
OPTIMISATION

CERTIFICATION / COMPLIANCE

TARGET
ACTUAL

FIND GAPS BETWEEN TARGETS & ACTUALS
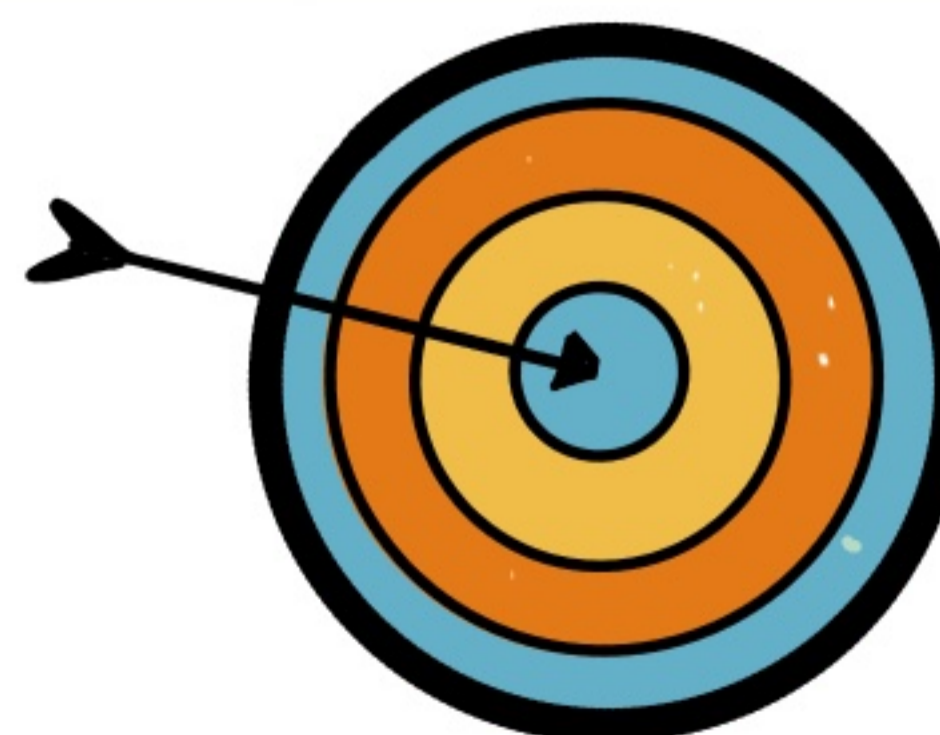
MEETING STANDARDS

GREENWASHING

GREENWASHING IS MAKING MISLEADING CLAIMS ABOUT THE POSITIVE CLIMATE IMPACT OF A PRODUCT, SERVICE, PRACTICE

GREENWASHING HELPS COMPANIES BOOST THEIR REPUTATION, SHARE PRICES AND PROFITS.

LABELS/LANGUAGE
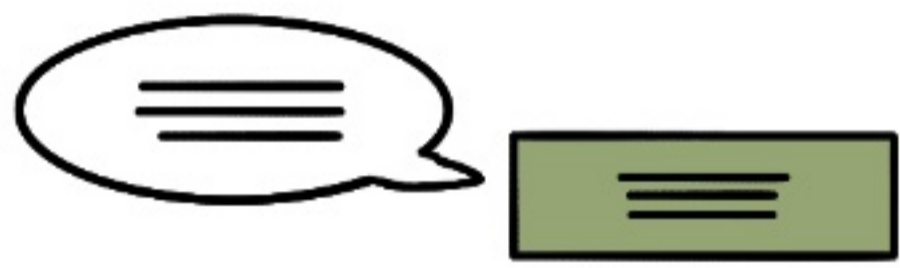
THE TERM CARBON FOOTPRINT WAS POPULARISED BY FOSSIL FUEL COMPANY BP - OFFLOADING THE BURDEN TO INDIVIDUALS WHILE THE LARGER ESTABLISHMENTS CONTINUED TO EMIT

NATURE- RELATED IMAGERY

USING PICTURES/WORDS TO LET PEOPLE THINK THAT SOMETHING IS CLOSER TO NATURE/CLIMATE FRIENDLY THAN IT REALLY IS

HIDDEN TRADE OFFS
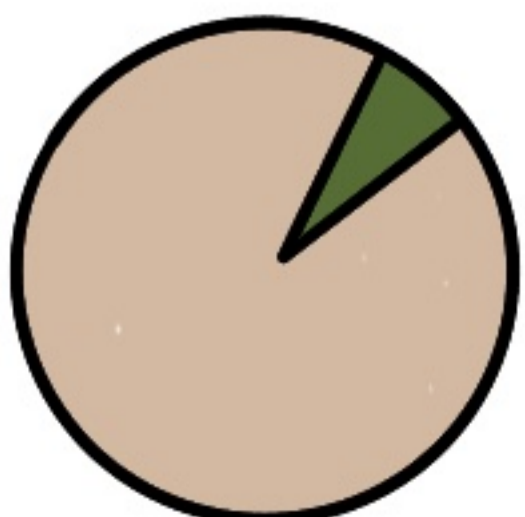
PUBLICISING ONLY ONE CLIMATE FRIENDLY ASPECT AND CONCEALING THE MANY THAT ARE ENVIRONMENTALLY HARMFUL

GREENWASHING

HERE ARE SOME MORE RELEVANT EXAMPLES

- INSUFFICIENT TARGETS
- PARTIAL REPORTING
- UNETHICAL CARBON OFFSETS
- HYPE OVER CARBON REMOVAL
- TOOLS THAT CLAIM TO EMIT LESS
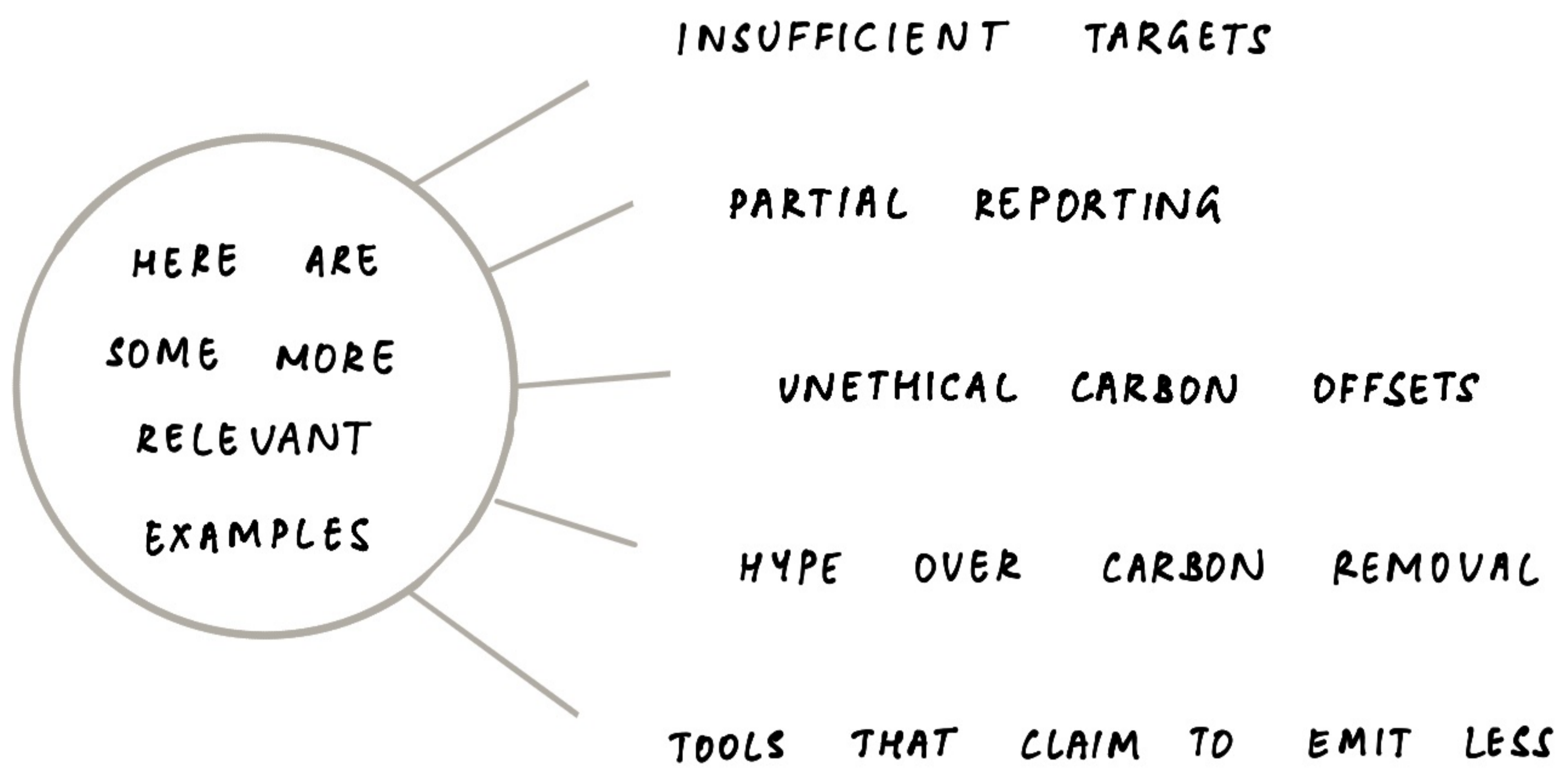
HOW NOT TO FALL PREY

- ✓ UNDERSTAND THAT GREENWASHING EXISTS
- ✓ LOOK FOR PROOF/CERTIFICATES TO SUPPORT CLAIMS
- ✓ BE CURIOUS ABOUT THE PRODUCT LIFECYCLE
- ✓ SUPPORT THOSE GENUINELY TRYING
- ✓ CALL IT OUT

CLIMATE RESILIENT DEVELOPMENT

CLIMATE RESILIENT DEVELOPMENT OR **CRD** IS A PROCESS OF IMPLEMENTING GHGS MITIGATION AND ADAPTATION OPTIONS TO SUPPORT SUSTAINABLE DEVELOPMENT FOR ALL

IPCC- INTERGOVERNMENT PANEL ON CLIMATE CHANGE IN ITS 6TH REPORT IN 2022 SAYS THAT **CRD** WILL BE ENABLED WHEN

GOVERNMENTS   SOCIETY   PRIVATE SECTOR.

MAKE INCLUSIVE DEVELOPMENT CHOICES

TO PRIORITISE

RISK REDUCTION

EQUITY

JUSTICE

WHERE THE PROCESS

FINANCES

ACTIONS

ARE ALL SYNCHRONOUS

ipcc·ch/report/ar6/wg2/resources/spm-headline-statements/
section D·2

WE CAN HOPE THAT HUMANITY MAKES THE RIGHT CHOICES

QUESTIONS TO PONDER

WHAT ACTIVITIES PRODUCE THE MOST EMISSIONS?
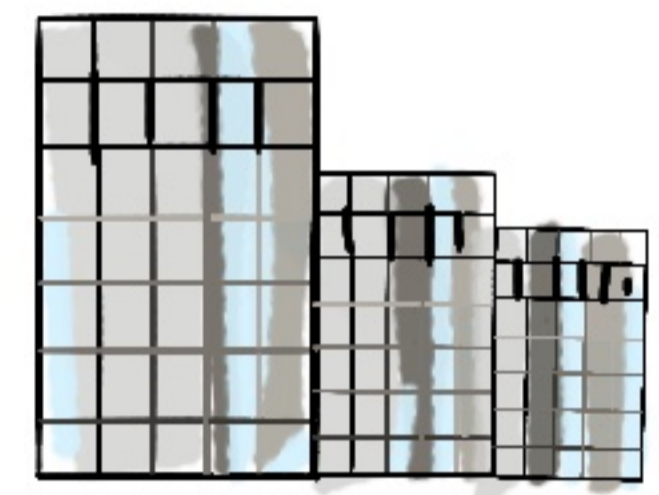
HOW DO WE SOLVE THE PROBLEM OF THE GREAT CARBON DIVIDE?

WHAT IS A COUNTRY'S PER CAPITA CARBON FOOTPRINT?

DOES NET ZERO BALANCE SCOPE 3 EMISSIONS TOO?

DO INDIVIDUAL CARBON FOOTPRINTS MATTER AS MUCH AS A CORPORATION'S? A NATION'S?

WHAT ARE THE TOP FEW NATURAL CARBON SINKS? (WAY TO ABSORB CO_2)

WHY IS IT SO UTTERLY HARD TO MEASURE SCOPE 3?

WHICH COUNTRIES BUY THE MOST CARBON OFFSETS AND WHICH SELL?

DEVICE PROLIFERATION AND LONG TERM EFFECTS

PENALTIES/LEGISLATION MAKE SUSTAINABILITY NON-NEGOTIABLE

IS CONTINUED INVESTMENT IN LLM SUSTAINABLE IN THE LONG TERM?

MY REFERENCES

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- Green Software Foundation Articles: https://greensoftware.foundation/articles
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- Building Green Software By Anne Currie, Sarah Hsu, Sara Bergman: O Reilly Early Release book

Measuring how Green

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Carbon Offsets/Removal

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- Why water usage is the datacentre industry's dirty little secret: https://www.computerweekly.com/