University of Glasgow

School of Computing Science

Low carbon computing

Context, vision and challenges

March 2022

Wim Vanderbauwhede

Global context

IPCC Sixth Assessment Reports:

- Greenhouse gas emissions must be cut drastically to keep global warming below 1.5°C (IPCC WGI AR6 report).
- They must be cut *now*, we can’t afford to wait anymore (IPCC WGI, “Physical Science Basis”, AR6 report).
- This is incompatible with unlimited economic growth (IPCC WG III, “Mitigation”, AR6 report).

The scale of the challenge

Meeting the climate targets

Limits and current emissions

- To limit global warming to below 1.5°C by 2040, a global reduction from 55 to 13 Gtonnes per year is needed.
- Emissions from electricity are currently about 10 $GtCO_2e$.
- But electricity consumption is rising steeply (electric vehicles, electric heating)

Renewables and nuclear

- Deployment is too slow
- It takes 20 years to build a new nuclear power plant
- Old ones are being shut down
- Renewables+nuclear will provide only 30% of electricity by 2040.

Carbon Capture and Sequestration

- The energy required in the capture process will be greater than the energy made available during the release of the CO_2.
- Many scenarios assume that large areas of land will be available -- not clear if this is realistic, scalable or compatible with sustainability goals.
- There are poorly quantified risks of re-release and no credible standards or compliance procedures.
- From an ethical and intergenerational justice perspective … it looks like green wash.

(taken from the UKRI DRI Net Zero presentation, M. Juckes, 2022)

Carbon offsetting

- The earth's land ecosystems can hold enough additional vegetation to absorb 40 - 100 GtCO_2e from the atmosphere.
- Once this additional growth is achieved (takes decades), there is no capacity for additional carbon storage on land.
- The world emits 50 GtCO_2e into the atmosphere per year. So all we can offset is 2 year's emissions at most.

Reducing emissions is imperative

- In other words, to reduce atmospheric CO_2 to 1.5C levels by 2040, the only way is
  - to reduce energy consumption
  - to reduce the amount of goods produced
- This is largely an economic problem, but there is an important role to play for technology

The carbon cost of computing

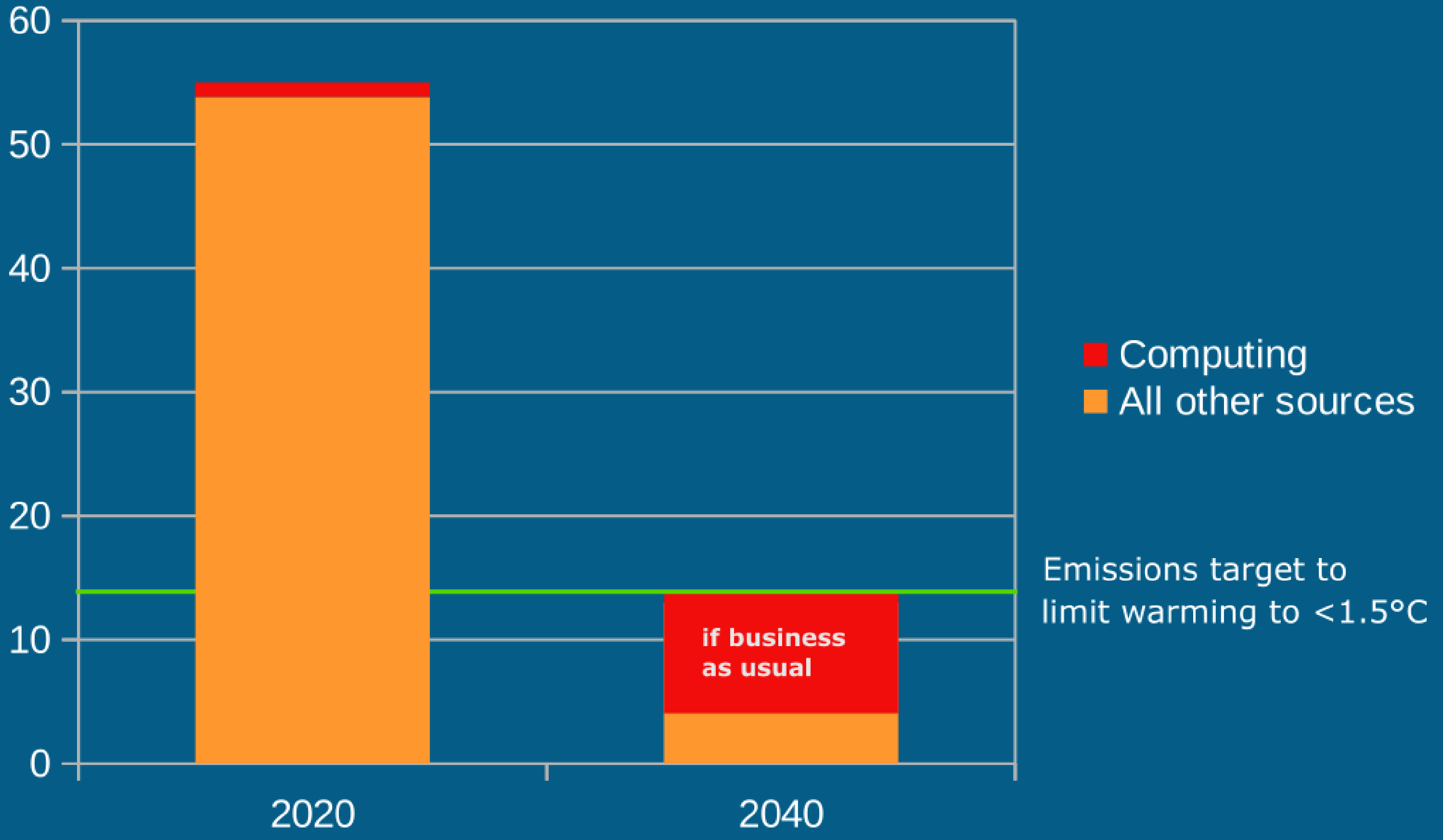
Emissions from using computing

- In 2020, emissions from using computing were between 3.0% and 3.5% of the total.
- This is already more than the airline industry
- By 2040 this will grow to 14% (4x).
- By 2040, energy consumption of compute devices would be responsible for 5 Gtonnes of CO_2

Emissions from production

- Emissions from the production of computing devices exceed those incurred during operation.
- Taking into account this carbon cost of production, computing would be responsible for 10 Gtonnes of CO_2 by 2040,
- This is almost 80% of the acceptable CO_2 emissions budget of 13 Gtonnes of CO_2.

Emissions from computing and other sources



Towards zero carbon computing

Transforming computing

- In less than two decades, we need a radically transformation of the global use of computational resources to meet the climate targets.
- We must dramatically reduce the carbon cost of both production and operation of computing.

Extending the useful life

- We can't rely on next-generation hardware technologies to save energy: the production of this next generation of devices will create more emissions than any operational gains can offset.
- This does not mean research into more efficient technologies should stop.
- But their deployment cycles should be much slower.
- Extending the useful life of compute technologies to several decades must become our priority.

Extending the useful life

- We need a change in business models as well as consumer attitudes. This requires:
  - raising awareness and education;
  - providing incentives for behavioural change;
  - provide economic incentives and policies;
  - infrastructure and training for repair and maintenance.

A vision for computing science

- Develop the computing science to extend the useful life of our devices and increase their capabilities.
- With every advance, effectiveness will increase without any increase in energy consumption.
- Computing technologies for the next generation of devices will increase energy efficiency and lifetime.
- Every subsequent cycle will last longer, until finally the world will have computing resources that last forever and hardly use any energy.

Specific challenges

Cloud computing

- Saving energy during operation:
  - Optimising for energy consumption: e.g. DVFS, accelerators, scheduling and placement
  - More energy-efficient software on all layers
- Increasing the useful life
  - Reliability monitoring and early-warning systems
  - Degradation-aware operation

Ultra-HD video & VR/AR

- Roll-out will lead to order of magnitude increase in video/3D traffic. To mitigate:
  - Better compression (e.g. tailored)
  - Local rendering (e.g. using FPGAs)
  - Better caching
  - Edge computing

IoT

- Project growth in devices is huge, resulting in huge increase in network traffic.
- Also huge emissions from production
- To mitigate:
  - Increase lifespan; reducing energy consumption helps primarily with this.
  - Edge computing to reduce network traffic.

Mobile devices

- Projected growth in mobile devices is still very large, and current lifespan much too short.
- Mainly needs longer-term software support, so better SE practices, in particular relating to security
- Apps should be designed to minimise full-system energy consumption
- User interfaces should nudge users towards energy efficient behaviour

Research directions

Systems

- Operating systems: energy-aware resource allocation and scheduling
- Networking: Energy consumption as QoS criterion
- Software engineering: better processes and sustainable practices will play a key role in extending lifetimes of systems.
- Data centre/cloud: energy efficient heterogeneous systems, resource allocation, scheduling, …

Information, Data and Analysis

- Sustainable systems need to be data-driven.
  - Large systems produce huge amounts of system data
  - Making sense of this data is crucial for whole-system energy optimisation
- Information retrieval is now pervasive.
  - Energy efficiency of IR systems (“greener search”), in terms of algorithms, software and hardware architecures.

Human-computer interaction

- HCI has a key role to play in achieving low carbon computing
  - Make users aware of energy/carbon costs of their actions
  - Nudge user behaviour towards more sustainable practice
  - Human-computer interfaces influence both energy consumption and useful life of devices

Formal Analysis, Theory and Algorithms

- Programming languages: resource-aware type systems with guarantees for resource bounds. Not a new idea, but worth revisiting within the current context
- Algorithms focussing on minimising overall minimal energy consumption
- Compilers: compilation for overall minimal energy consumption: not just CPU, also RAM, DMA, I/O wait, …

Computing Science Education

- We teach our students how to program, we teach them about all aspects of Computing Sciene
- But currently, we don't teach them about the impact of computing on climate change, nor how to make computing sustainable
- There is a lot of scope in our curriculum for incorporating ILOs on decarbonisation and sustainability
- All our programs should have such ILOs

Thank you!

For more details and references

https://wimvanderbauwhede.github.io/articles/frugal-computing/