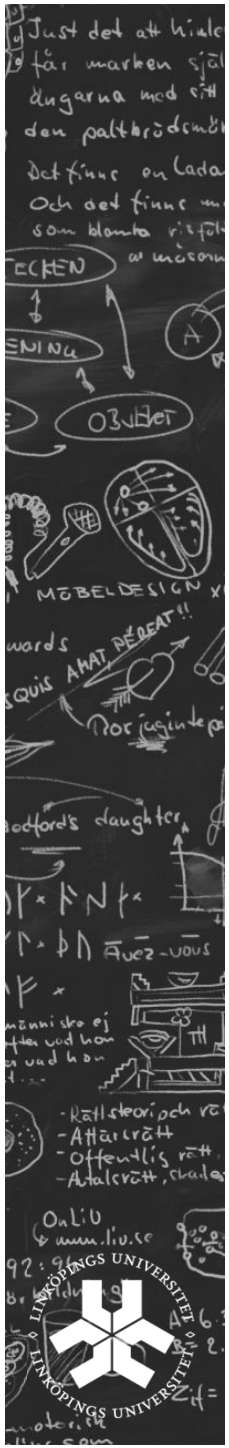
Green Computing
TDDD50

www.ida.liu.se/~TDDD50

Cybersecurity Division
Department of Computer and Information Science (IDA)
Linköping University
Sweden

January 19th, 2026

LiU expanding reality



Course Staff

- Examiner & Course leader

  Simin Nadjm-Tehrani

- Course assistant

  Willem Meijer (Contact for web/Lisam information)

- Seminar teachers (Contact for absence from seminars)

  Willem Meijer (Group B and F)

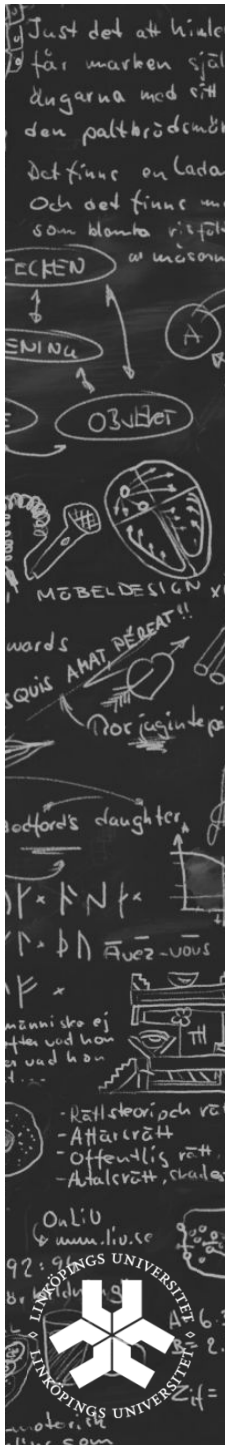
  Federica Uccello (Group C and D)

  Simin Nadjm-Tehrani (Group A)

  Buse Atli (Group E)

- Course administrator (mails to: adm-gu@ida.liu.se)

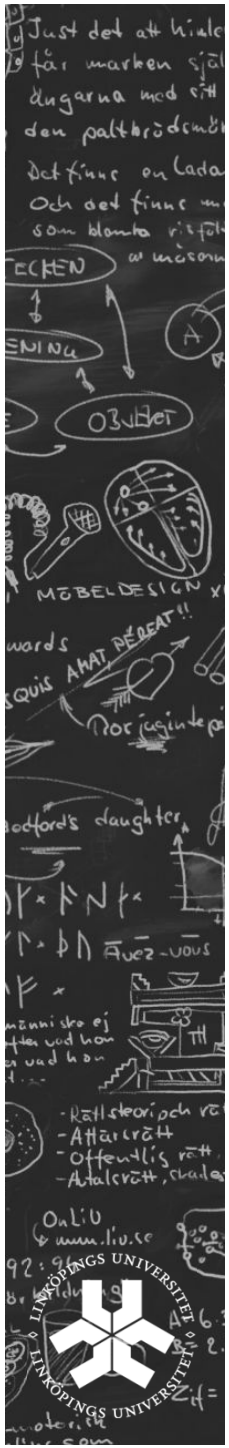
  Mention the course code (All Ladok-related matters!)



Structure of the course

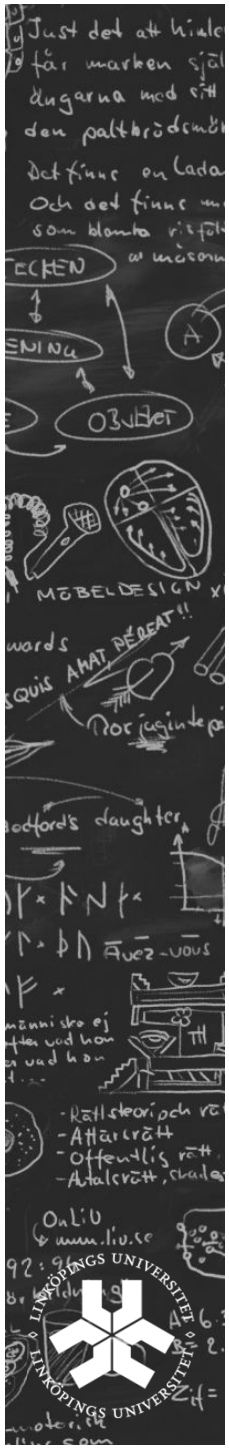
- Lectures
  - 3 orientation lectures
    - Introduction to the course, rules of the game, minimum terminology to start you off discussing in seminars with relevant terms and concepts!
- Group Seminars
  - 1 introductory seminar (*seminar 0*) – “Learn how to do it” where teachers act as a presenting student
  - 6 regular seminars (11 research papers) – presentation by students

All seminars obligatory!



Seminar Group formation

- Please register in webreg initially!
  - **Deadline: 20/1**
  - **This means you are committed to take the course in the present period**
- When the number of participants is final we may move a couple of students between the groups
- Groups are expected to be finalised at latest by 22/1
- Due to major organisation effort and obligatory seminars and discussions the set-up is sensitive to later drop-outs
  - please do not register in webreg if you are not sure you are going to take part in the course

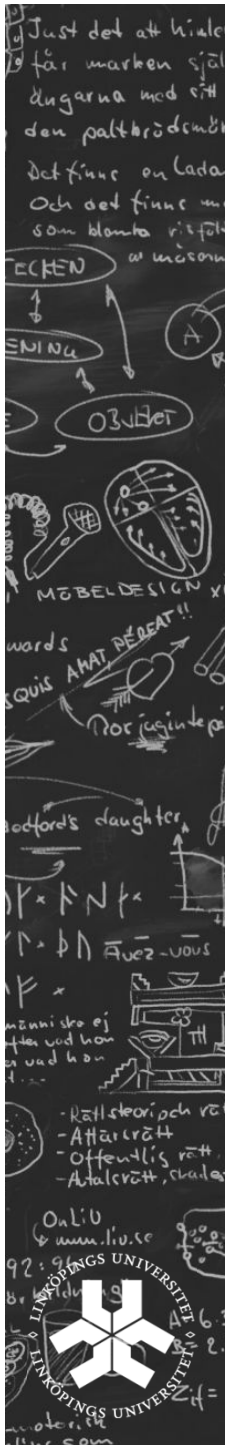


Course goals

- Identify and analyze the global sustainability impacts of information & communication technologies (ICT)
  - ICT carbon footprint
  - product lifecycle
  - standards

All in English!

- Identify mechanisms for reducing energy consumption of ICT
- Analyze sustainable ICT solutions/products
- Learn to read research papers, present it *verbally*, and lead a discussion in a group. Learn to critically evaluate outcomes of experiments by discussing them
- Learn to write a research summary and discuss it in a *scientific style* and find related articles

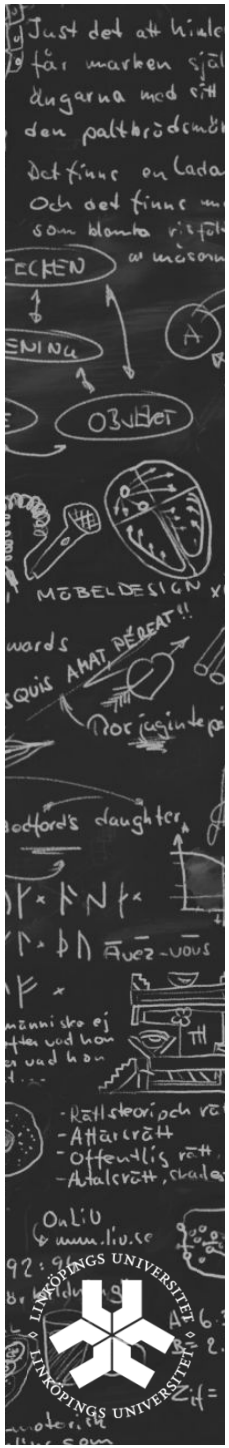


Why Green Computing?

- LiU started this course in 2010
- Today, EU has a strategy to be climate neutral by 2050

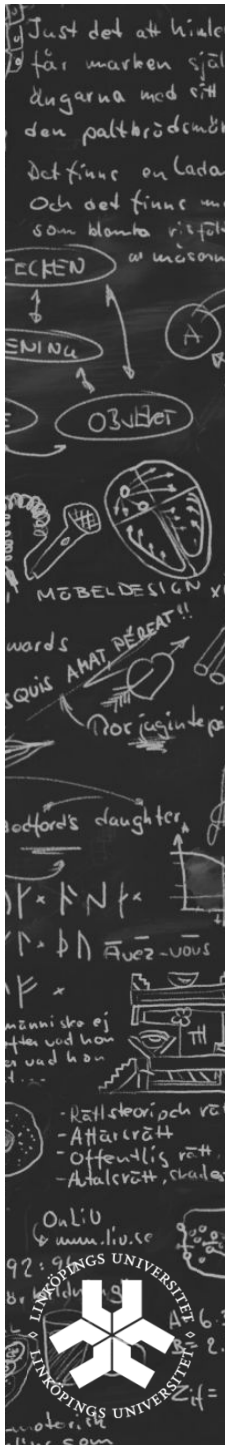
https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

- Does ICT have a role to play in this?



Degree goals

- For Swedish students (UKÄs utbildningsmål)
- Civing (och högskoleing.):
  - “insikt i aktuellt forsknings- och utvecklingsarbete”
  - ”utveckla och utforma produkter, processer och system med hänsyn till … samhällets mål för ekonomiskt, socialt och ekologiskt hållbar utveckling”
  - ”förmåga att i såväl nationella som internationella sammanhang muntligt och skriftligt i dialog med olika grupper klart redogöra för och diskutera **sina** slutsatser”
- So we are right on the spot here!
- Check the learning goals in the course syllabus to see how communication skills are combined with technology!

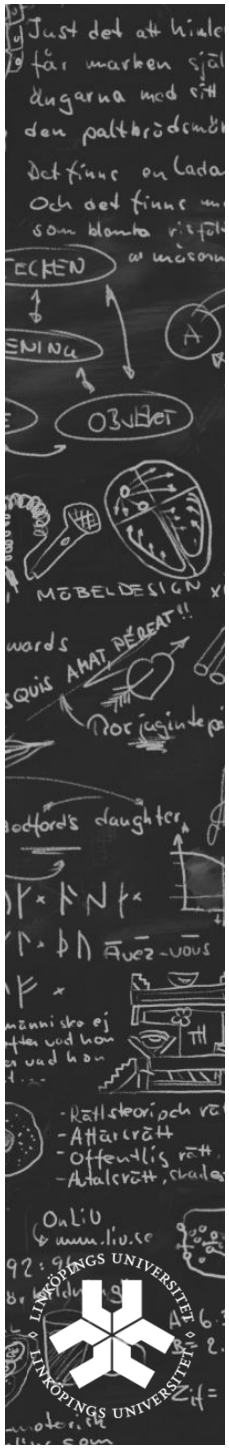


Technology-economy-ecology intertwined

- Over a lifetime, you need to make sense of complex phenomena and this is a good beginning to practice

- Here is an input to current policy decisions in Sweden (available also in English):

https://policyinstitutet.se/2025/05/26/ny-policy-brief-el-till-varje-pris/

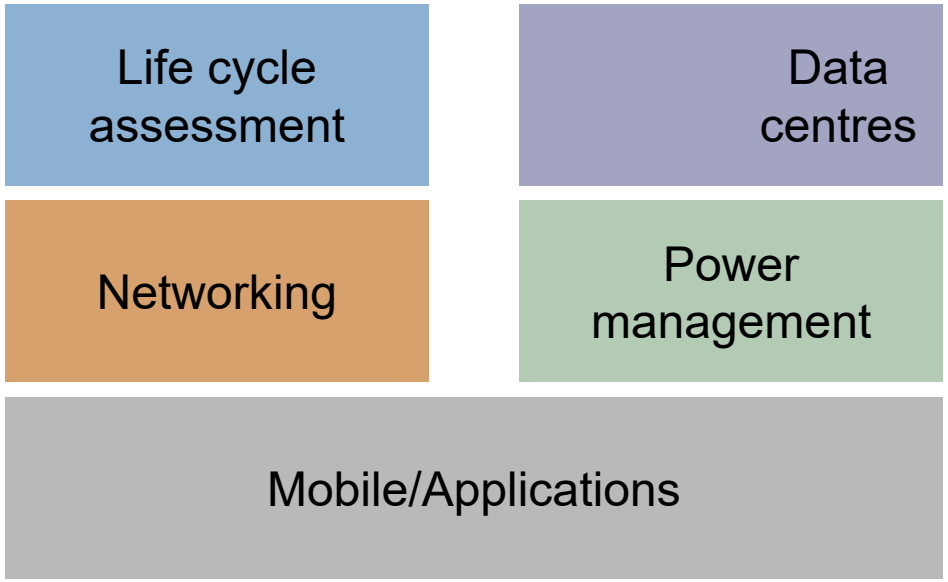


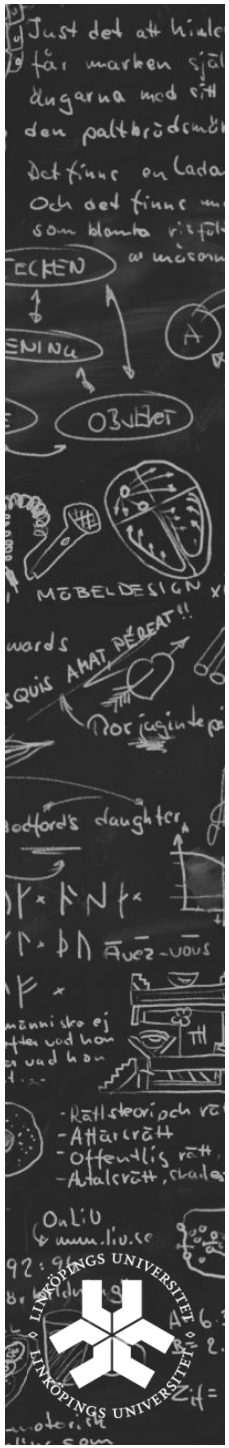
Topic overview

- The course articles are linked in the course website
  - Seminar section:

http://www.ida.liu.se/~TDDD50/seminars

- The topics seminars will focus on are:





Two types of information in lectures

- Guidelines and content
  - How can a student prepare to pass this course?

  - What is the basic terminology one is expected to know to actively take part in the seminars and use in own report?

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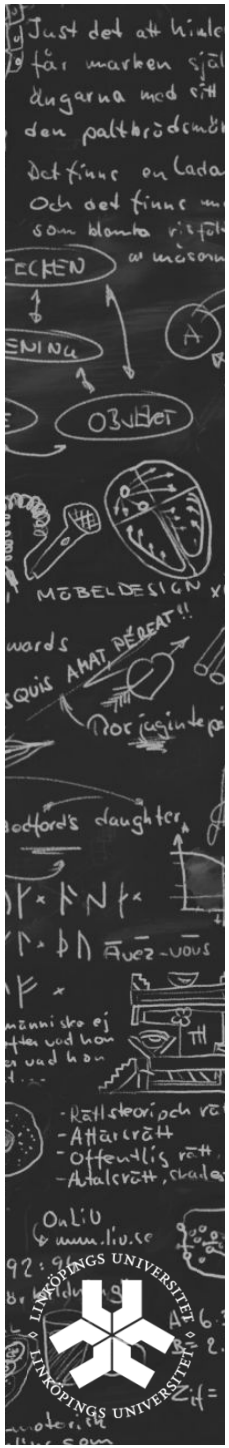
http://openclipart.org/detail/75799/registry-book-by-wakro



Examination

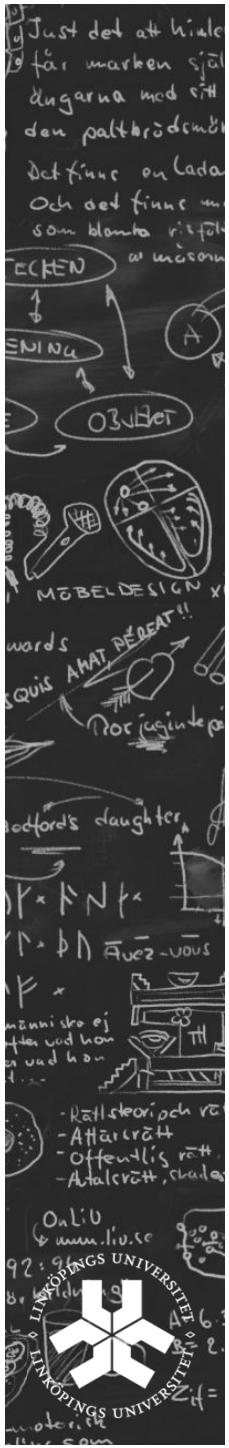
- Own presentation of **one** assigned (own) article, with the group members as participants and teacher as observer/evaluator (UPG2, 1hp)

Combination for UPG3 (3hp):

- Full presence and *active participation* in seminars, discussing other students' articles

- Written report in scientific style on the own article with a *discussion of the content* of that paper showing your deep understanding, and connecting to discussions in class

- Retakes for all parts: June and August



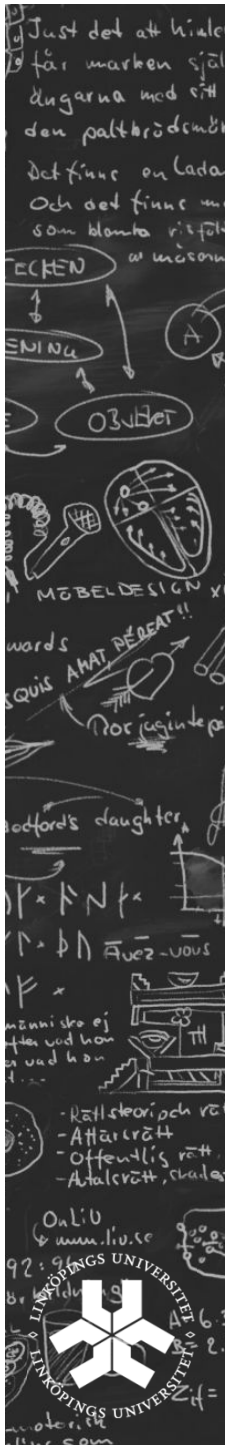
What is active participation?

A student actively participating (grade 3):

- Has browsed through the paper to be presented by another student before the seminar and knows what it is about, has a copy of the paper discussed open in class
- Has prepared 2 questions specific to that paper to be shared with others *before* the discussion starts
- Uses roughly 1/10 of the available discussion time

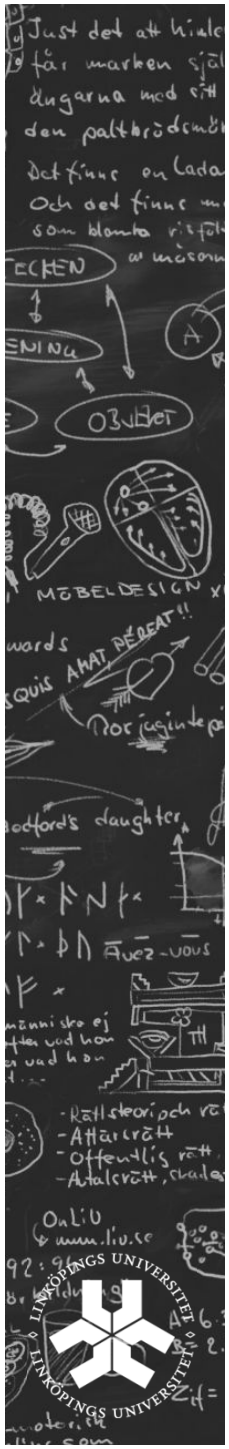
Grades 4 and 5:

- Uses precise terminology that appears in course material
- During the seminar, refers to tables, curves, sections to make discussions more concrete
- Listens, takes notes, clarifies questions, answers other students' questions



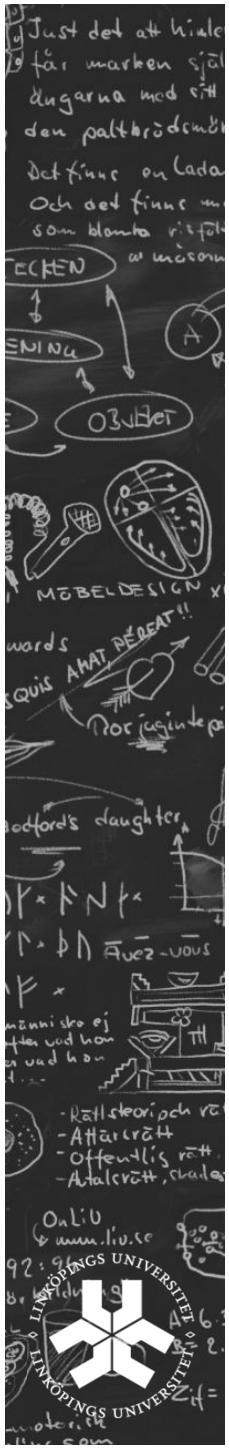
Absence from seminars

- Absence from a seminar = Not learning the content of the papers discussed in *that* seminar
- Two types of absence:
  - **Illegitimate** absence; leads to failing the seminar part of UPG3
  - **legitimate** absence (= sickness), if you sent a mail to your teacher in advance
- Both will result in additional work for the absent student and teachers (additional written report on missed articles)
- Difference between legitimate absence and illegitimate absence:
  - Only those with no absence or max two legitimate participation absences can pass the course in VT1
  - Others will attend retake sessions in June/August



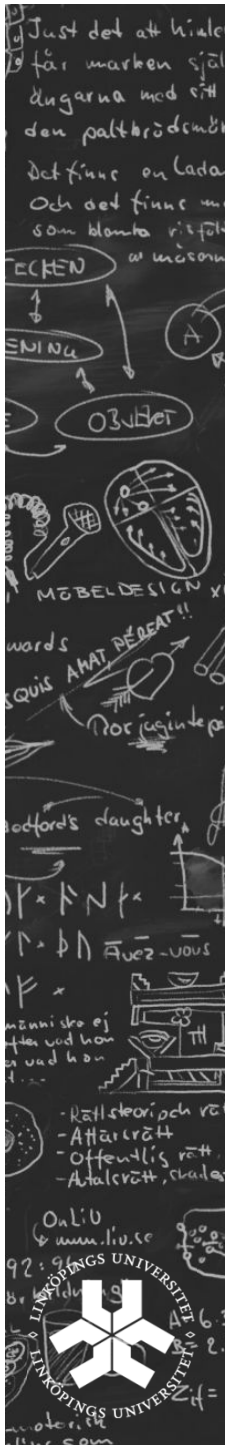
Selection of your article

- While selecting the article you would like to present, keep in mind that:
  - Each article is assigned to a fixed session (date)
  - Articles require different background knowledge (specified on the course web page)
- Select 3 articles in the order of preference and send mail to your webreg **group teacher**, **deadline: 21/1**
- Mark your mail subject: “TDDD50: article selection”
  - Then refer to the article numbers: e.g. [7] IEEE 802.3az…
- Articles are assigned based on email timestamp (FIFO)



Grades: incremental requirements

- **Grade 3**
  - Satisfactory presentation and leading of discussion for the (own) assigned article
  - Attending all seminars and participating in discussions
  - Satisfactory report about the assigned article (see template on the web page!) and two related research articles found
- **Grade 4**
  - High quality discussion of the assigned article in own report
  - Higher quality of activity in the discussions, more relevant questions, answers grounded in the paper, more answering of others' questions
- **Grade 5**
  - One additional section in own report including:
    - Suggestion of an alternative idea on the paper's solution
    - At least one more related work reference to discuss



Important dates and procedures

Before 20th January	**Register in webreg**
Before 21nd January	Preference about article sent to (prel.) Grp teacher
22nd January	Group formation
Latest: 22nd January	Article assignments
27th January	Introductory seminar (sem 0 - obligatory)
2nd February	First article presentation (sem1)

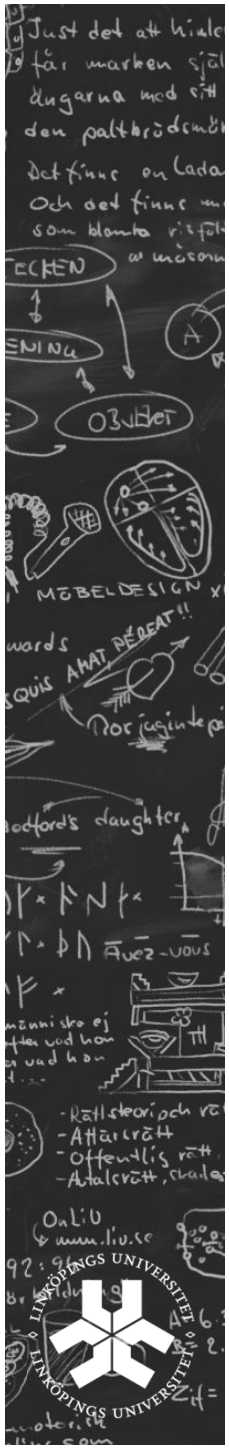
- Within two (three) weeks from your presentation send v1 of your report!

Datacentre visit

- Was organised in previous years
- To see real stuff in Mjärdevi

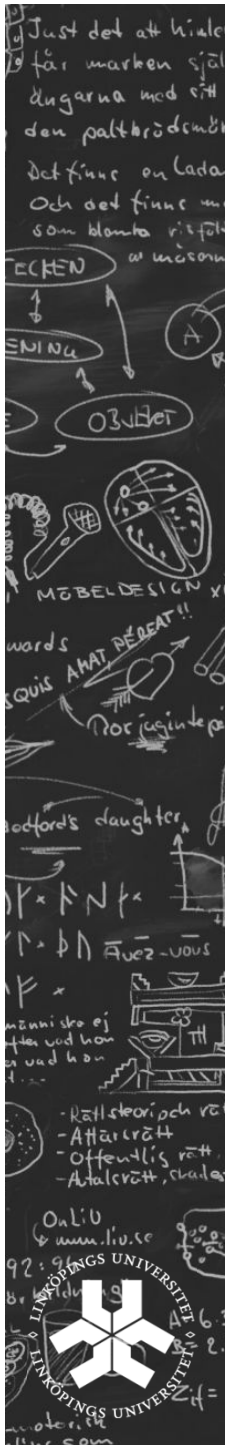
- Will only be organised if there is enough interest, more info via mail

Source: NSC



Course evaluations (VT25)

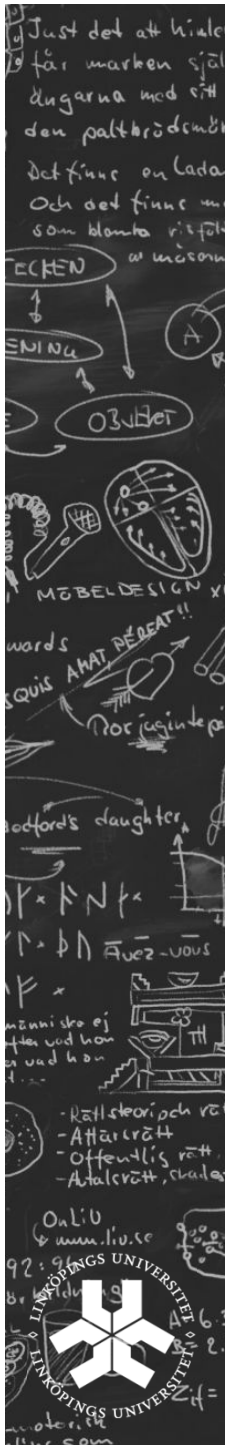
- There is report from the Ling evaluation and dialog that should be accessible to you from “sektionen”
- Main points were Relevance, Grading, and Feedback.



Relevance

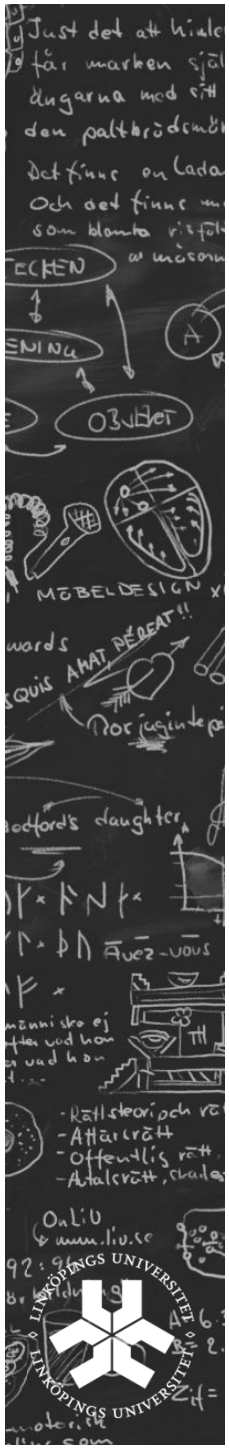
- Divided views: Some students thought that the course was relevant from an environmental perspective, and others thought that the non-technical goals are not relevant to engineering students - “coding is more fun than writing reports and presenting”

- Comment:
  - It is true the technical content can be learnt independently from the learning goals that relate to reading and writing of scientific text and verbal presentation
  - The degree goals imply that if not here, those goals would have to be combined with the bachelor thesis course (with no previous practice)



Grading

- Some students thought that it was easy to fail presentations and/or the report, and that different teachers had different limits
- Comments:
  - We do a lot of off-stage coordination to ensure that the four teachers see the task in a similar way, many times compare different reports and comments with each other. All borderlines are discussed in group.
  - Some impressions are due to the uneven background/skills of students, and some due to uneven nature of articles.
  - We try to counter the latter by 1) allowing you to choose article, 2) removing some sections of the longer articles, 3) putting the harder articles in later weeks so that those students have a longer calendar time to learn from watching/discussing

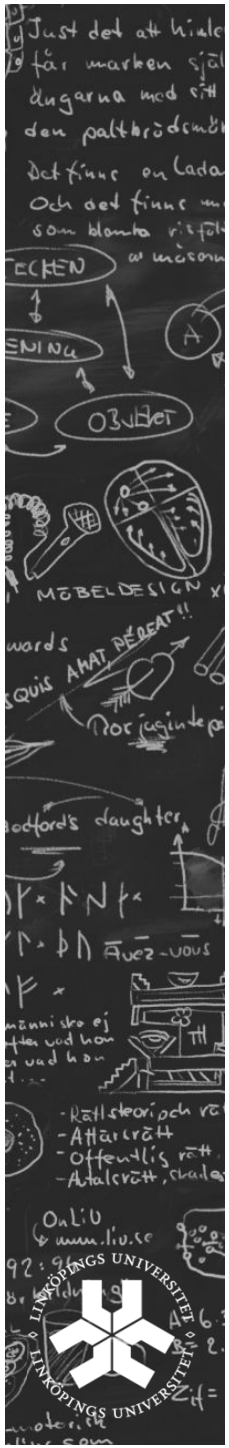


Outcomes of last year

- 50 of 62 (in six groups) passed UPG2 in VT1 (80%)

- 7 got grade 5 from UPG3 (in VT1)
- 21 got grade 4 from UPG3 (in VT1),
- 26 got grade 3 from UPG3 (in VT1).
- That is a total of 54 (87%).

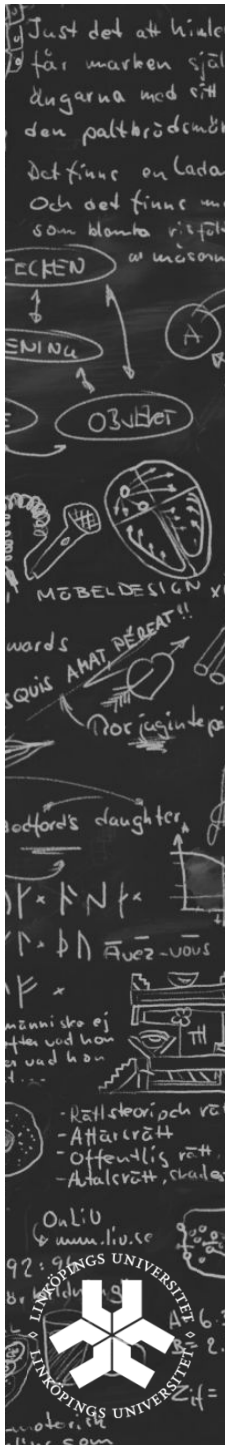
- The total course (kursbetyg) was passed by 48 people (>77%).



Feedback

- Did not get feedback on participation and was unsure how well one was doing. Did not know what type of questions to ask.

- Comments:
  - The guidelines in seminar 0 are supposed to help you learn which types of questions are preferred (see also slide 12 here)
  - The level (P or P+ or U) is determined after **all** participation has taken place, and we are not able to give continuous individual feedback for 10 participations to 60+ students
  - If you are anywhere close to a U after a couple of seminars you will be contacted by teachers to give you hints on how to improve.



Means to help and general advice

- Take notes during seminar 0 and if not sure about any recommendations/rules after that ask your teachers so you can prepare well!
- To help us see what content you are struggling with ask about specific technical contents of your article as opposed to spending loads of time *on your own*!
- Use the option of sending the (complete) draft of your presentation before the actual occasion to get help/feedback!

Thesis projects

- Consider this area as a possible topic for your thesis project!

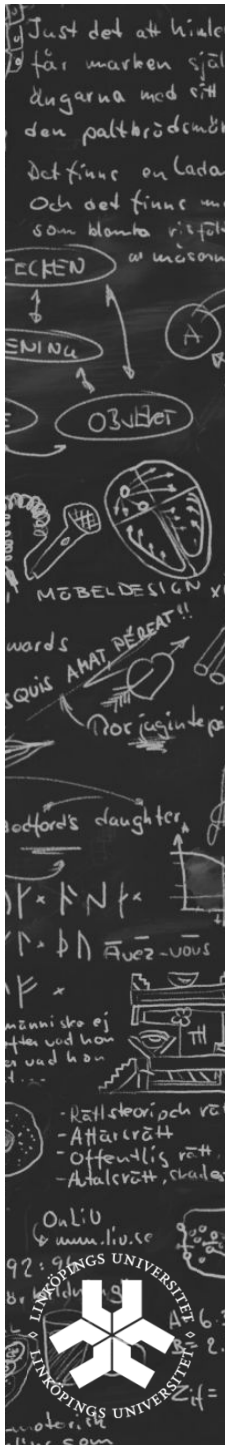
Anton Thomasson

M. Asplund, A. Thomasson, E. J. Vergara, and S. Nadjm-Tehrani,
Software-related Energy Footprint of a Wireless Broadband Module,
Proceedings of *9th ACM International Symposium on Mobility Management and Wireless Access (MobiWac)*, ACM, November 2011.

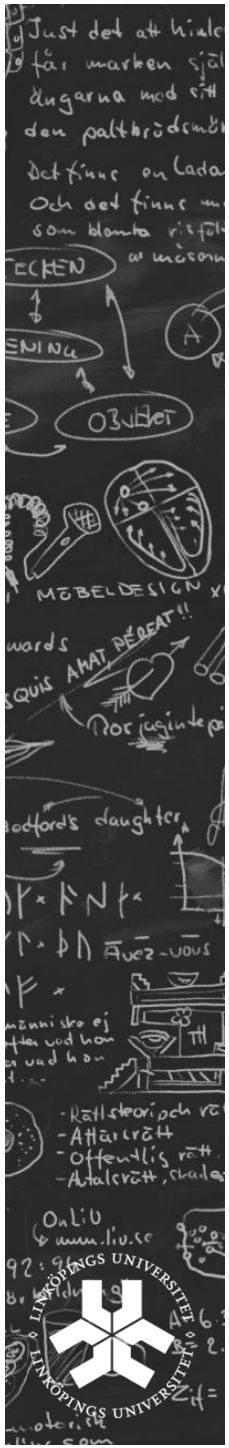
Best student thesis prize

- Awarded by Computer Society (Dataföreningen) 2013
- You have Simon's published paper in the e-energy 2014 conference in your seminar series :-)

More prizes for theses defended



Questions?



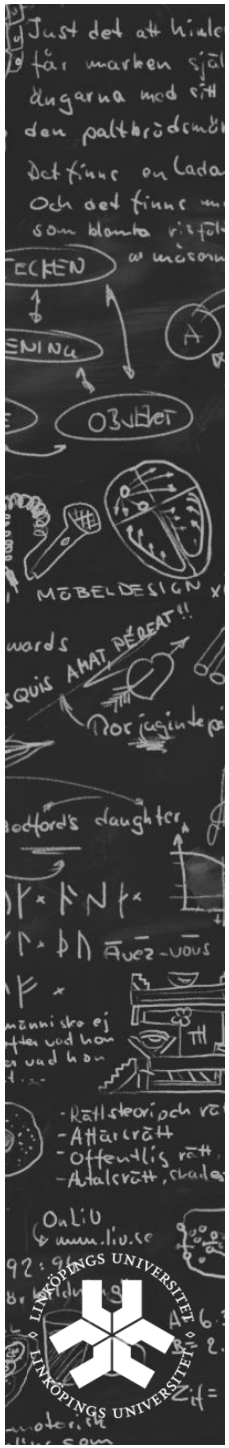
Terminology

- Introduction to sustainability
- Life-Cycle of ICT products
- Eco-labelling and standards

Many thanks to Jordi Cucurull
For earlier versions of this course material

Terminology

- **Introduction to sustainability**
- Life-Cycle of ICT products
- Eco-labelling and standards



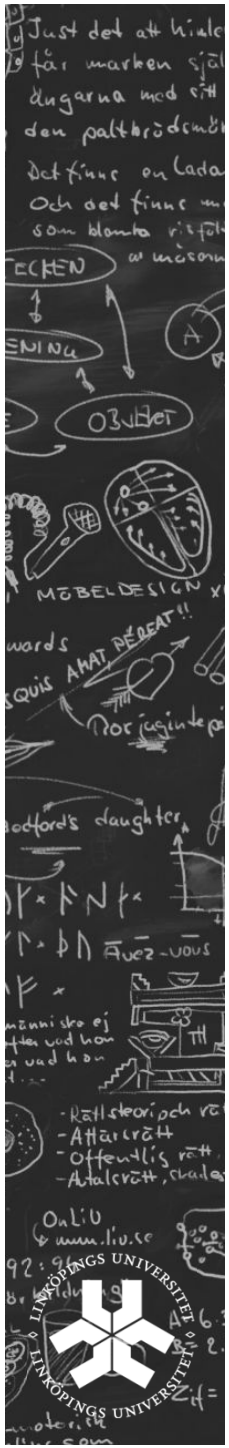
Long term is important!

- Sustainable development is a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”

  Brundtland report (1987)

UN sustainability goals (SDGs)

http://www.un.org/sustainabledevelopment/sustainable-development-goals/



Recall: Education degree goals

- Civilingenjör

”visa förmåga att *utveckla och utforma* produkter, processer och system med hänsyn till människors förutsättningar och behov och samhällets mål för ekonomiskt, socialt och ekologiskt hållbar utveckling.”

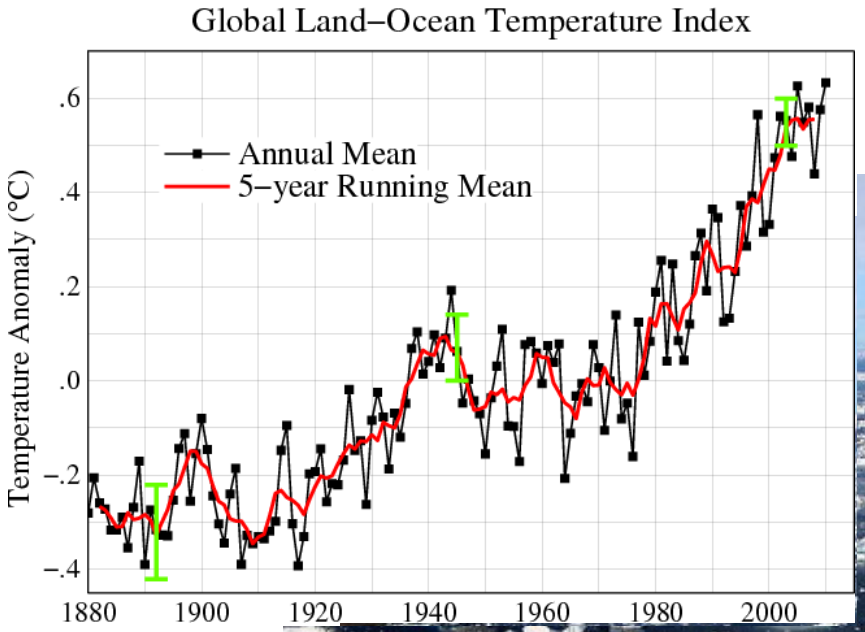
- Dataingenjör

”visa förmåga att *utforma och hantera* produkter, processer och system med hänsyn till människors förutsättningar och behov och samhällets mål för ekonomiskt, socialt och ekologiskt hållbar utveckling.”

Global Warming

- Human activities are affecting the natural environment
- An example is the massive production of CO_2

Global Warming



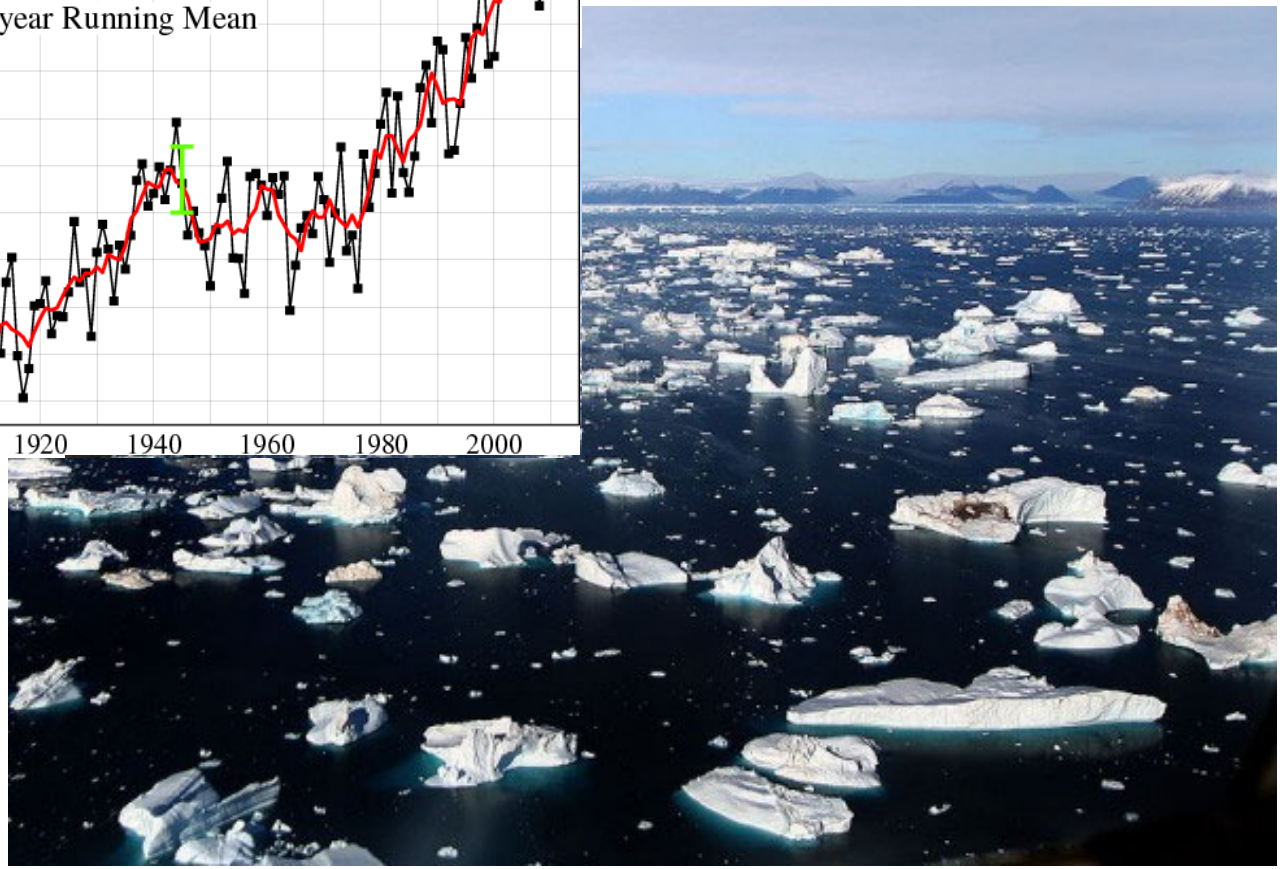
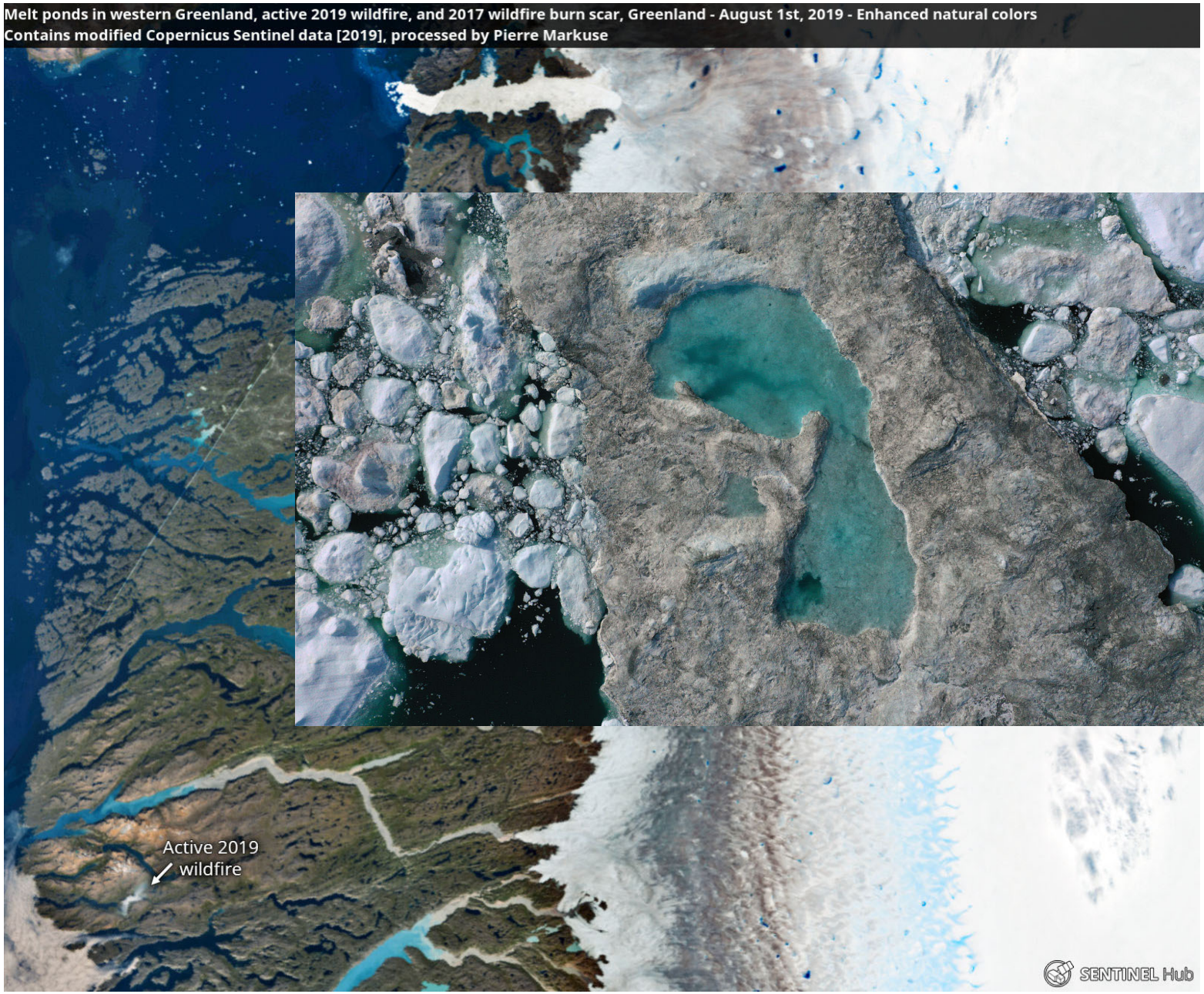


Photo by Mila Zinkova [CC-BY-SA-3.0 (www.creativecommons.org/licenses/by-sa/3.0)]



Source: https://earther.gizmodo.com/this-satellite-image-shows-everything-wrong-with-greenl-1836919989

Technology can bring positive change

Kapaia installation at Hawaii (Bloomberg News 2017)

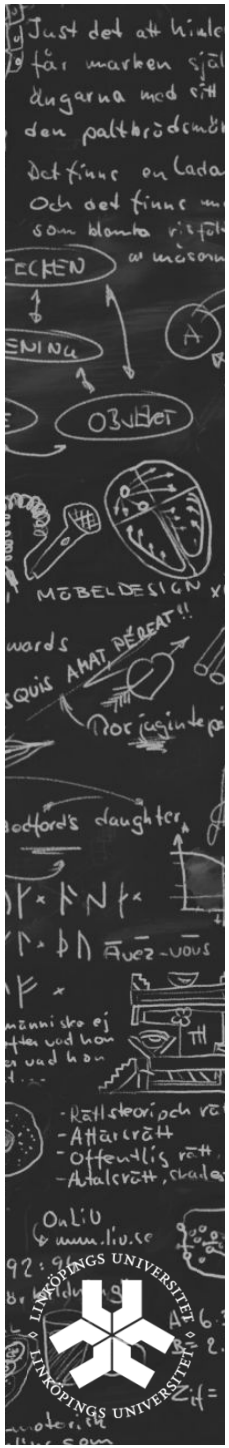
- Cheaper solar power and storage in batteries

Technology has also a footprint itself!

Technology companies cannot be oblivious to this change!

“while total data traffic has increased by about 80 times between 2007 and 2023, the ICT sector used only 1.4 times more electricity.“

Ericsson blog November 2025

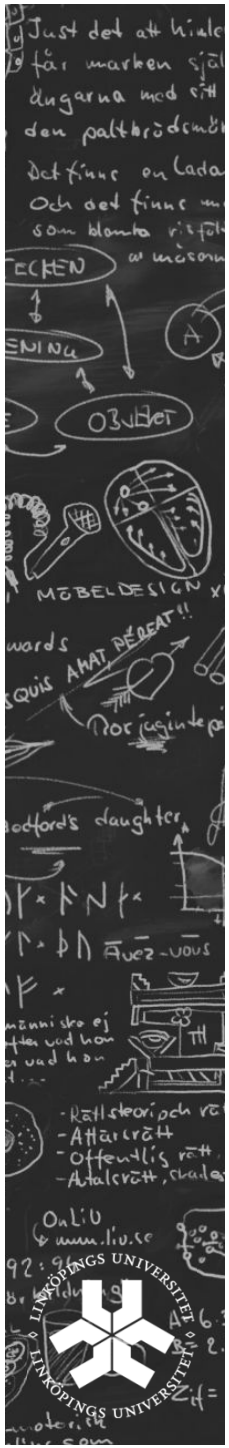


But also unforeseen effects…

AI safety Report, January 2025:

- Baidu reports that increased energy requirements due to the “rapid development of LLMs” are posing “severe challenges” to their development of green data centres
- Google similarly reports a 17% increase in data centre energy consumption in 2023 over 2022 and a 37% increase in GHG emissions due to energy use “despite considerable efforts and progress on carbon-free energy”

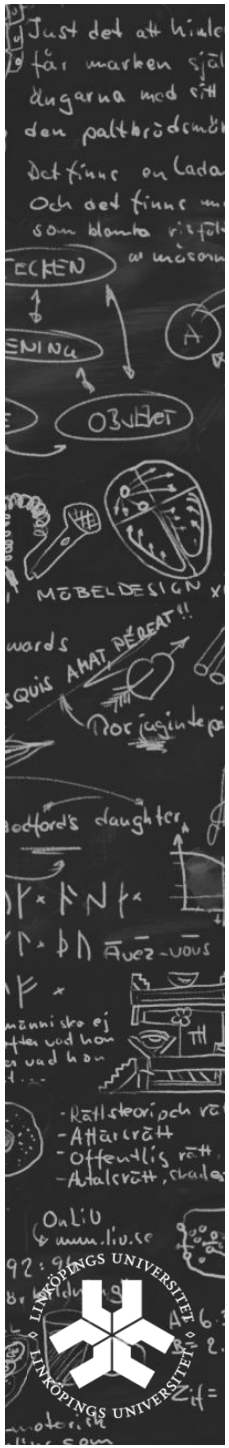
- They attribute these increases to increased investment in AI



Think about the scale!

- Search driven by GenAI uses 4-5 times the energy of a conventional web search

https://www.nature.com/articles/d41586-024-00478-x.pdf



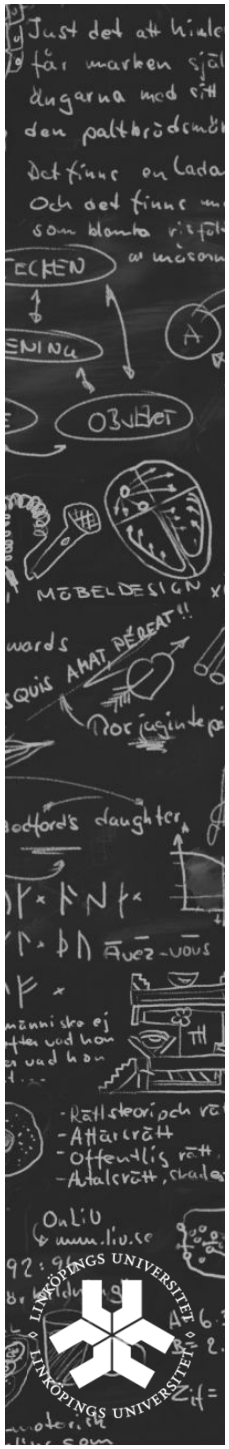
MIT technology review

- Was early to bring light to AI energy footprint

https://www.technologyreview.com/2019/06/06/239031/training-a-single-ai-model-can-emit-as-much-carbon-as-five-cars-in-their-lifetimes/

- Refers to a report where a NLP model training is compared to 5 cars in their entire life-time in terms of CO2 footprint:

  Strubell et al. 2019: https://aclanthology.org/P19-1355/

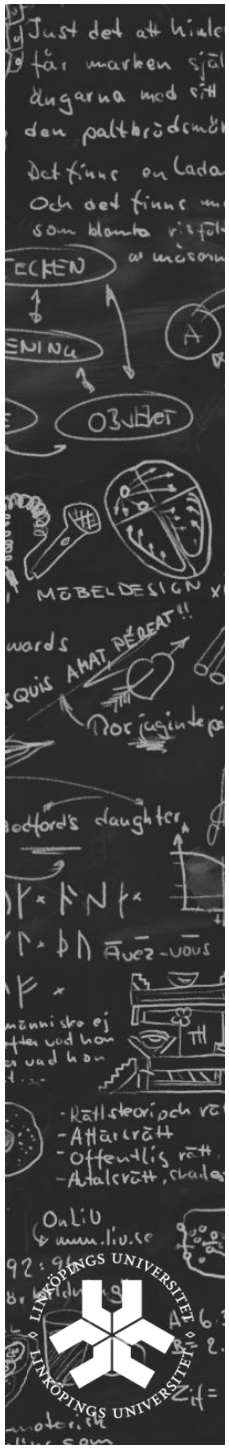


Computing within LIMITS

- Which future trajectory to base computing research on?
- Planet-scale limits are ignored in the growth-based vision of the future
- Shift from material productivity to long term well-being!

[Nardi et al. 2018]

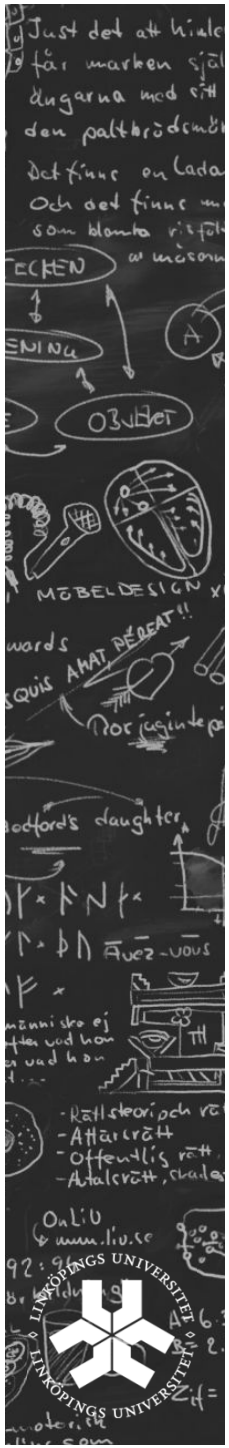
doi.org/10.1145/3183582



New notion: “Sufficiency”

- ”Any strategy that directly aims at decreasing the absolute level of resource and energy use by reducing the levels of production and consumption”

Santarius *et al*. *2022*
https://doi.org/10.1007/s12243-022-00914-x

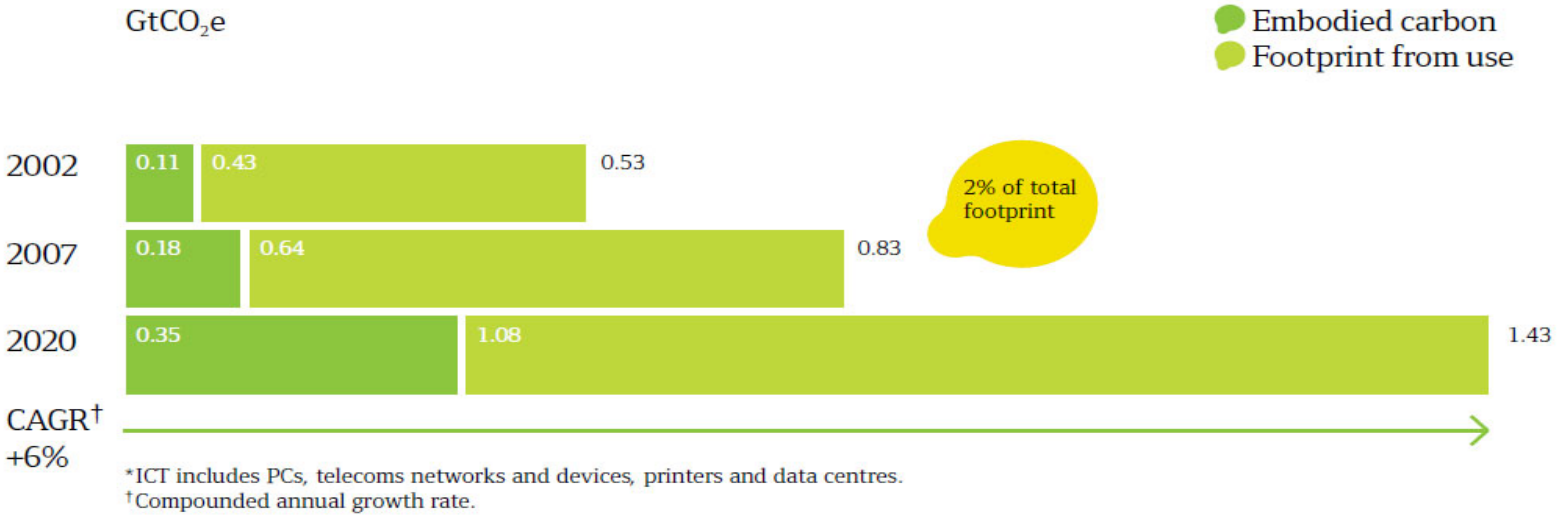


Green ICT vs. ICT for Green

- ICT for Green
  - Use ICT technologies to reduce the environmental footprint of other processes and sectors
  - E.g., smart grid, smart building, smart transportation, smart health, smart education,…

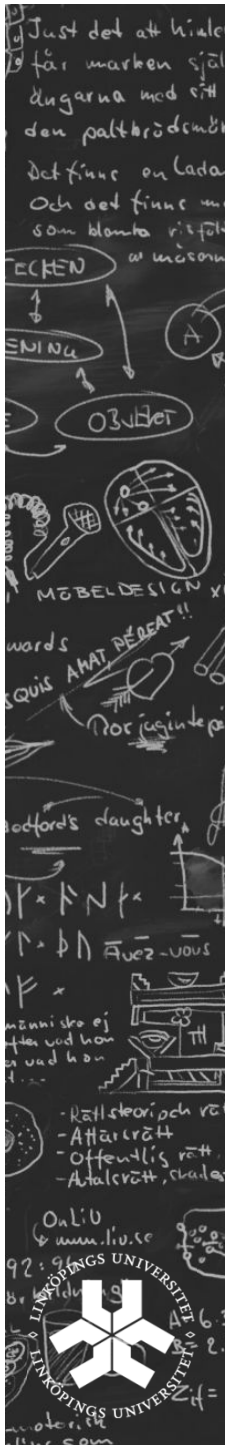
- Green ICT
  - Reduction of the ICT's environmental footprint
  - E.g., Energy-aware data centers

Global ICT footprint (CO_2)



From the 2008 report of the Climate Group: https://www.theclimategroup.org/news/smart2020

- 2018: Digital technologies now emit 4% of Green House Gases, and their share is expected to increase to 8% by 2025
  https://theshiftproject.org/wp-content/uploads/2019/07/2019-02.pdf
- We already reached 8% in 2022!
  https://dl.acm.org/doi/pdf/10.1145/3613207



Other sources of data

- Clicking clean 2017: ICT is globally estimated to use 7% of the world's electricity

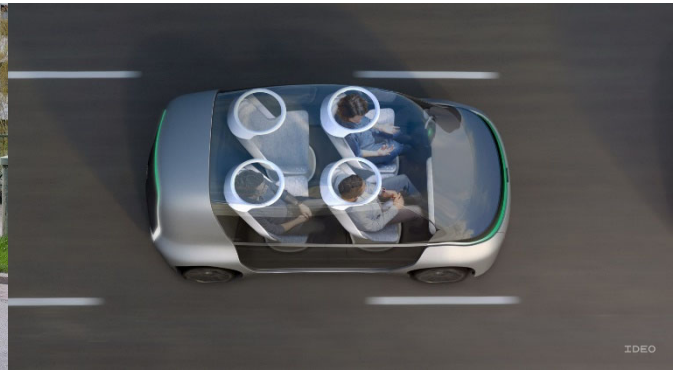
- ICT is responsible for 8-10% of Europe's electricity consumption, and 4% of its Carbon emissions

http://www.europarl.europa.eu/factsheets/en/sheet/69/energy-efficiency

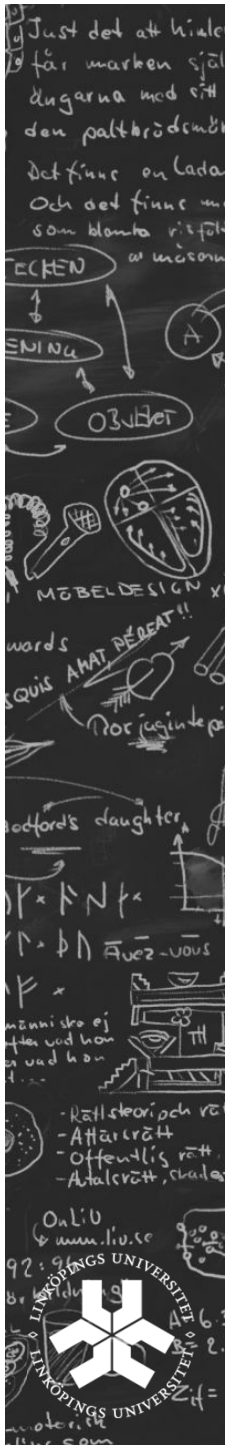
- Internet traffic footprint (2024)

https://dl.acm.org/doi/abs/10.1145/3699843.3699846

Green ICT vs. ICT for Green



- Future transportation:
  - ICT for Green or Green ICT?



Definition of Green Computing

Different definitions are possible:

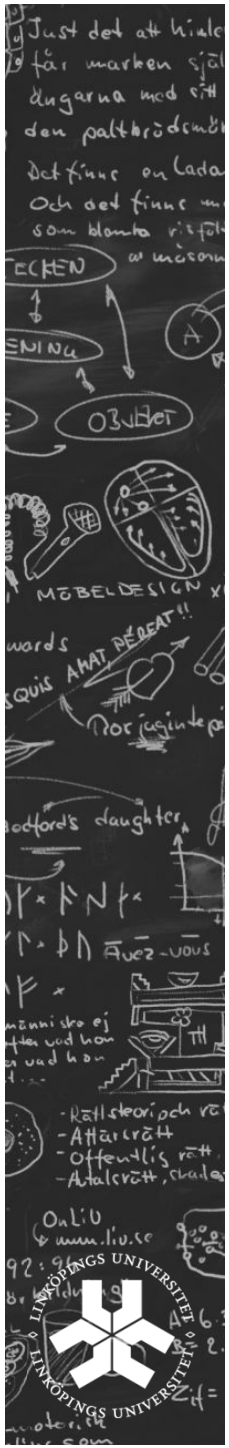
- Reduction of the environmental impact, e.g. by reduction of Green House Gases (GHG)
- Reduction of energy waste
- Reduction of energy bill
- Reduction of energy consumption

While maintaining (or considering the loss in) the quality of service

Ways of achieving each

- Reduction of the environmental impact
  - Use renewable energy sources (GHG emissions)
  - Design of low power components
  - Responsible disposal and recycling
- Reduction of energy waste
- Reduction of energy bill
- Reduction of energy consumption

Source: http://www.renewableenergyworld.com/rea/tech/hydropower



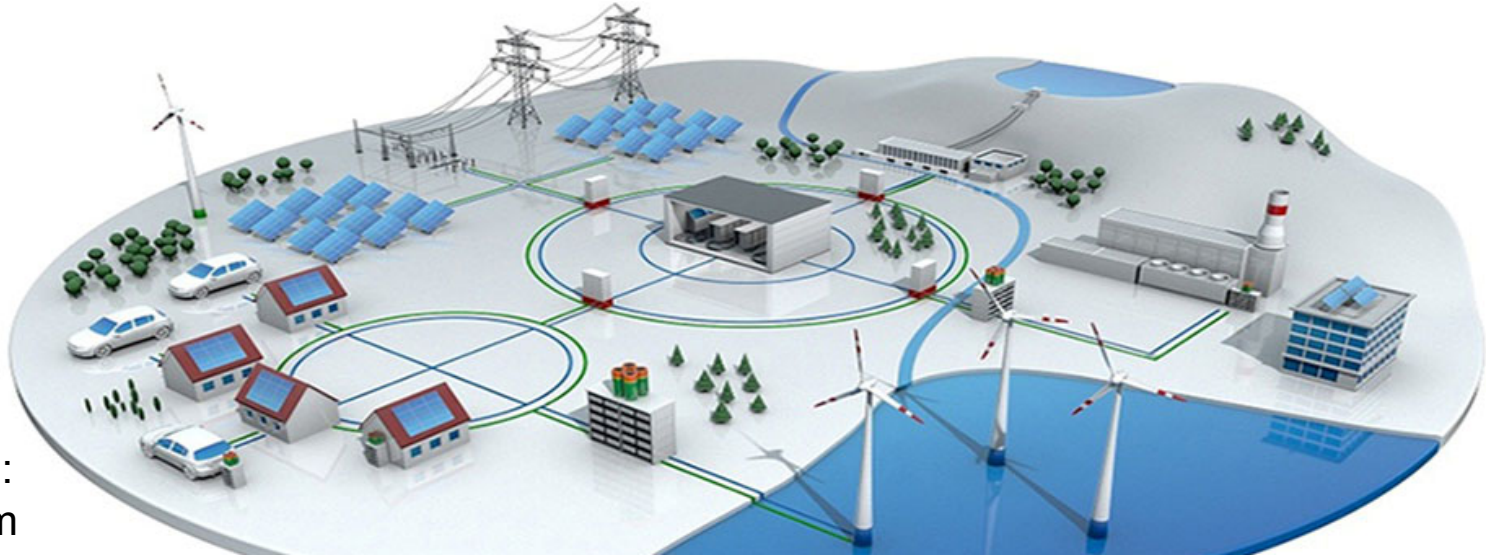
Ways of achieving each

- Reduction of the environmental impact
- Reduction of energy waste
  - Locate power drain points close to power plants
  - Exploit environmental characteristics (e.g., cooling, sun)
- Reduction of energy bill
- Reduction of energy consumpt

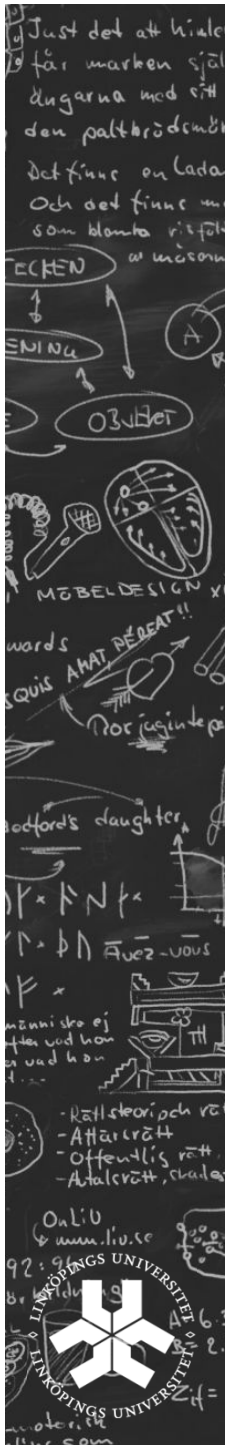
Source: https://www.facebook.com/LuleaDataCenter

Ways of achieving each

- Reduction of the environmental impact
- Reduction of energy waste
- Reduction of energy bill
  - Exploit volatile electricity prices
  - Create and enforce regulatory support

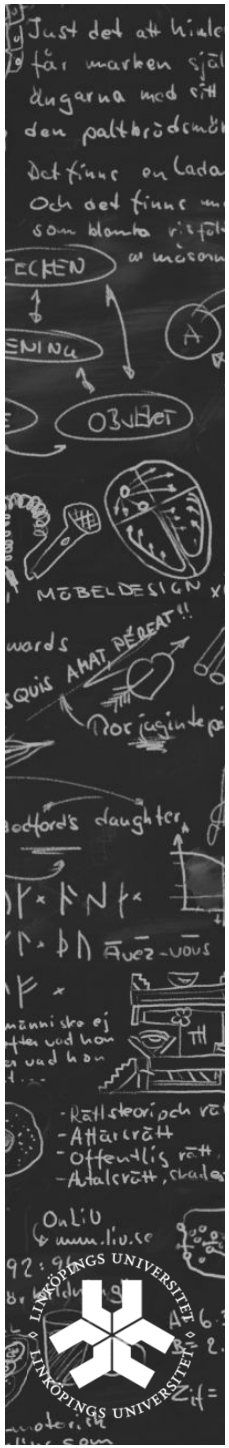


Source: 3M.com



Ways of achieving each

- Reduction of the environmental impact
- Reduction of energy waste
- Reduction of energy bill
- Reduction of energy consumption
  - Enforce energy proportionality
  - But … Consider performance guarantees



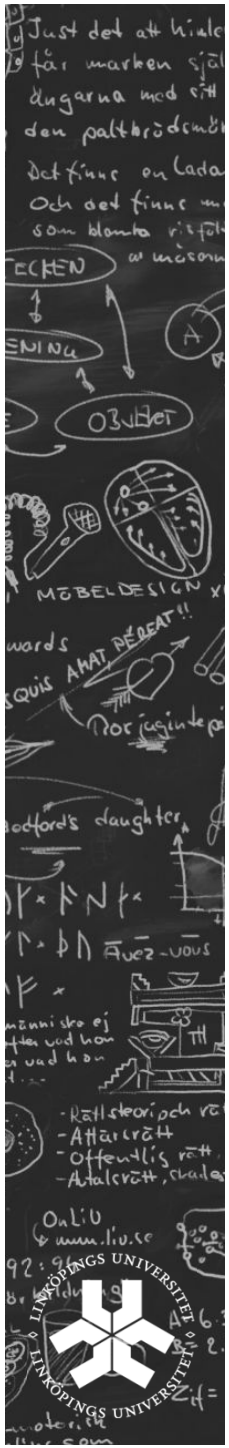
Benefits (cross-definition)

- Environmental
  - ICT respectful towards the environment
  - Less production of CO_2 and other contaminants
- Economical
  - Reduction of electricity bill
  - Less infrastructure for same service (power supplies, cooling systems...)
  - Government financial incentives
- Public relations
  - Marketing, Competitiveness

    https://www.cdp.net/en/companies/companies-scores

Corporate advocacy

- https://www.ericsson.com/en/about-us/sustainability-and-corporate-responsibility/sustainability-report
- https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2021



What consumers can do to cut energy

- March 2023 report
  - Naturreverse
  - Enerconomy
  - S(AI)fe keepers
  - … and more

https://www.ericsson.com/en/reports-and-papers/consumerlab/reports/10-hot-consumer-trends-climate-change-impacting-consumers

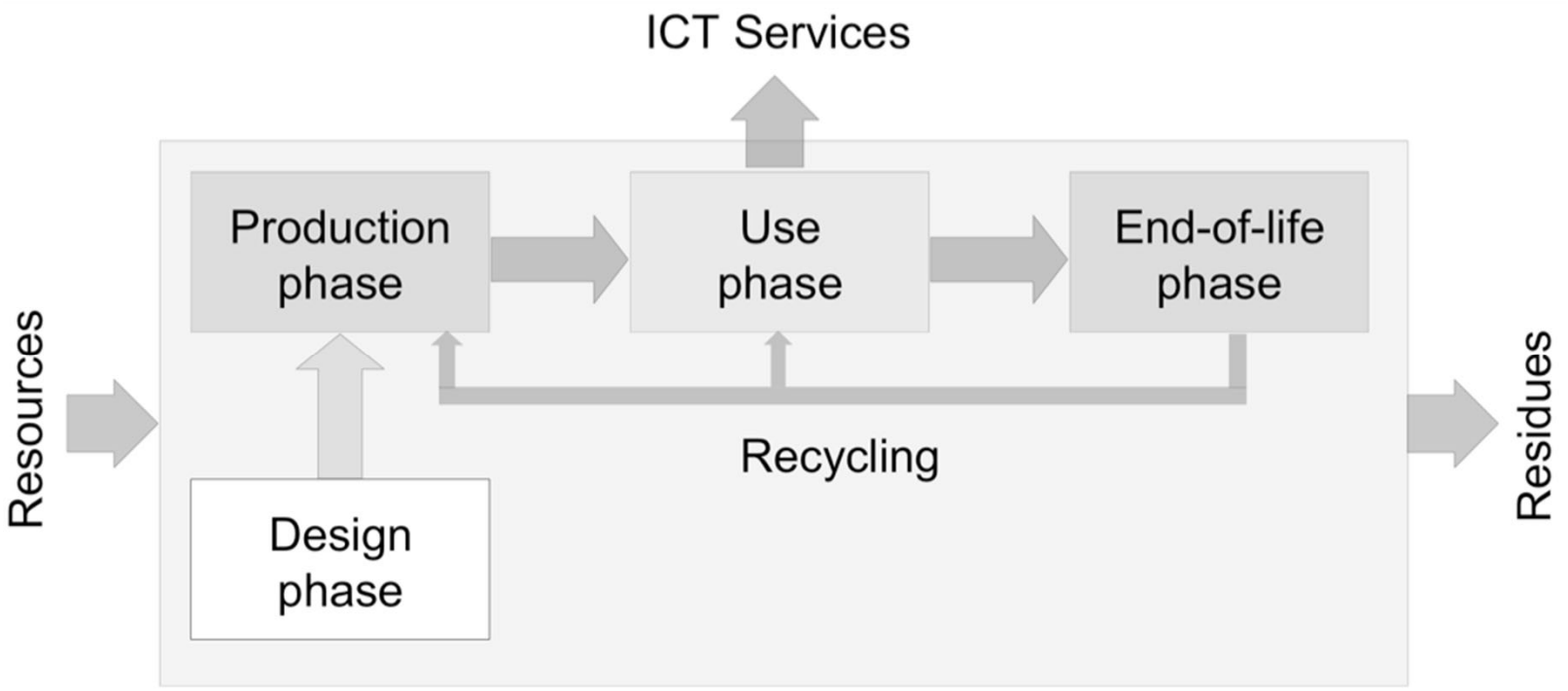
Sustainability affects company's image

- https://www.greenpeace.org/usa/oil-in-the-cloud/
- https://www.greenpeace.org/usa/click-clean-virginia/
- https://www.greenpeace.org/usa/rethinkit/
- https://www.greenpeace.org/usa/greener-electronics-2017-2/

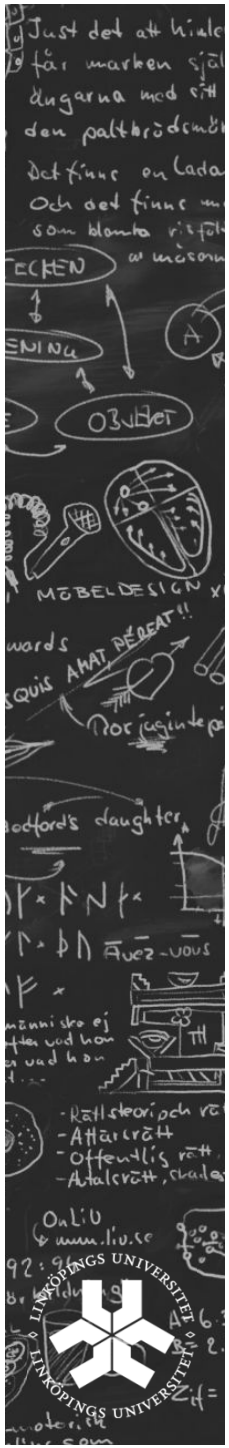
Terminology

- Introduction to sustainability
- **Life-Cycle of ICT products**
- Eco-labelling and standards

Holistic approach: Life-Cycle of ICT



Lorenz M. Hilty. Information Technology and Sustainability: Essays on the Relationship between Information Technology and Sustainable Development, Books on Demand, 2008 ISBN: 978-3837019704



Life-Cycle Assessment (LCA)

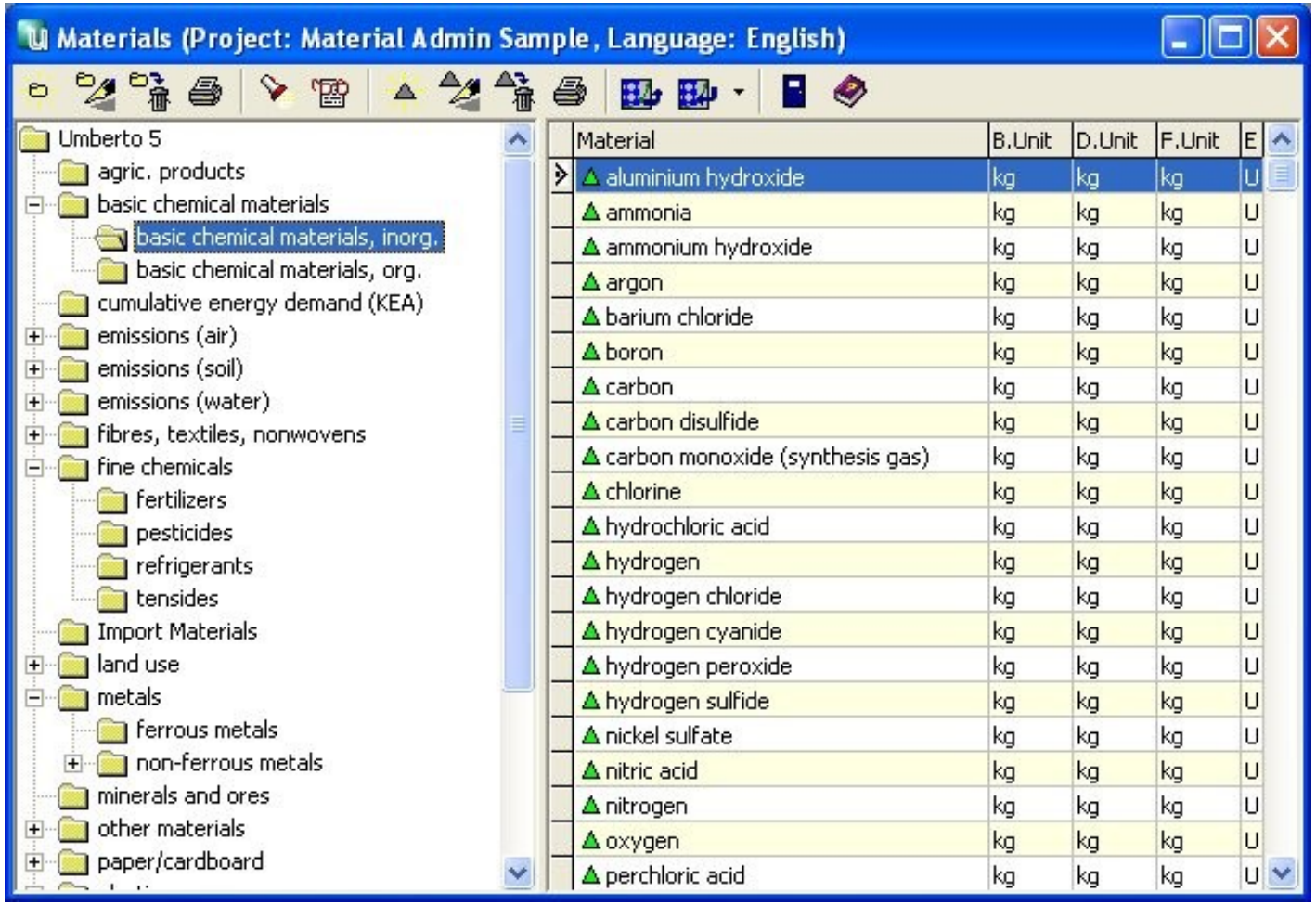
- All phases of the chain must be considered
  - Consumption of material and energy
  - Use of some infrastructure
  - Materials, energy and infrastructure have their own life-cycles
  - Recursive study of them

- LCA analysis performed with
  - LCA tools: *SimaPro*, *Umberto*...
  - Life-cycle inventory database: *Ecoinvent*...

https://www.youtube.com/watch?v=pPOZAWNO4PE

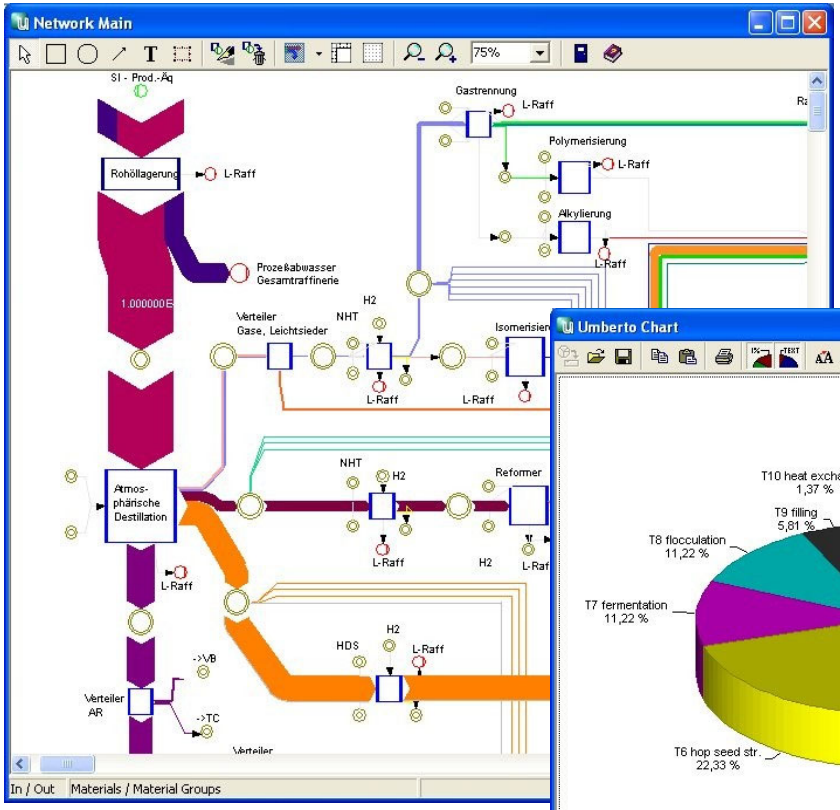
Umberto (i)

Management of materials



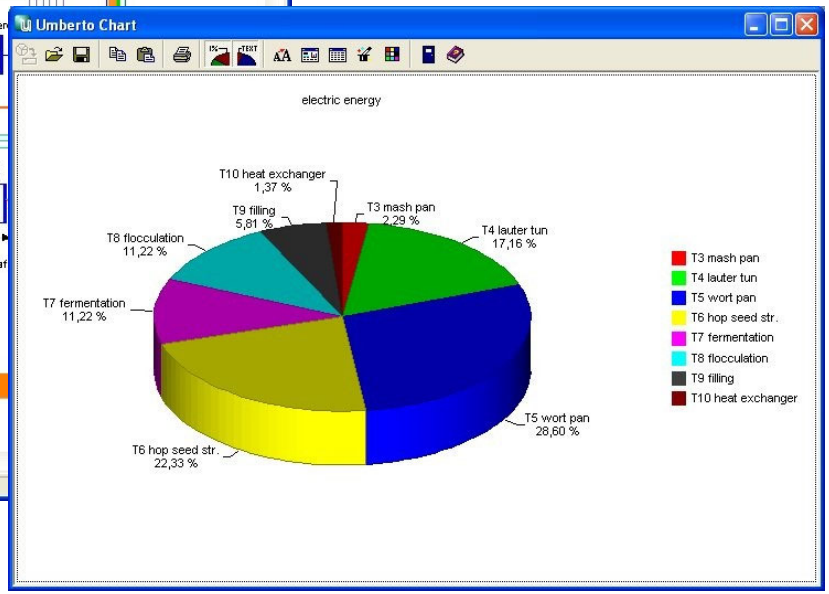
http://www.umberto.de

Umberto (ii)



Material flows

Electrical energy spent

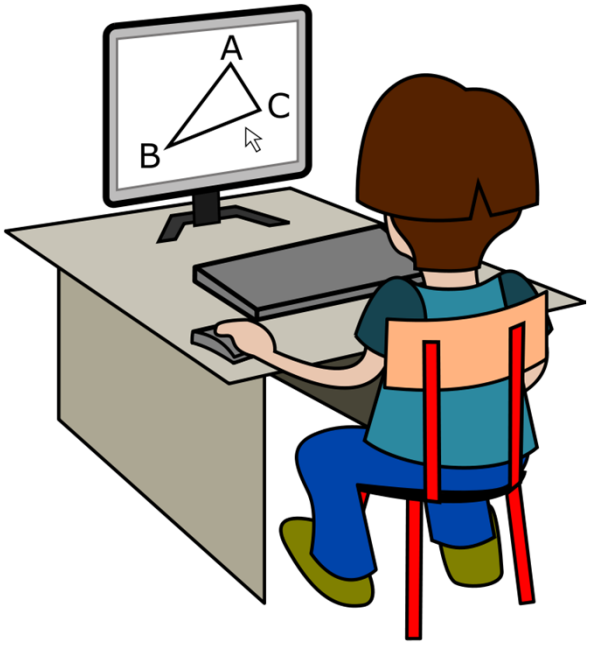


http://www.umberto.de

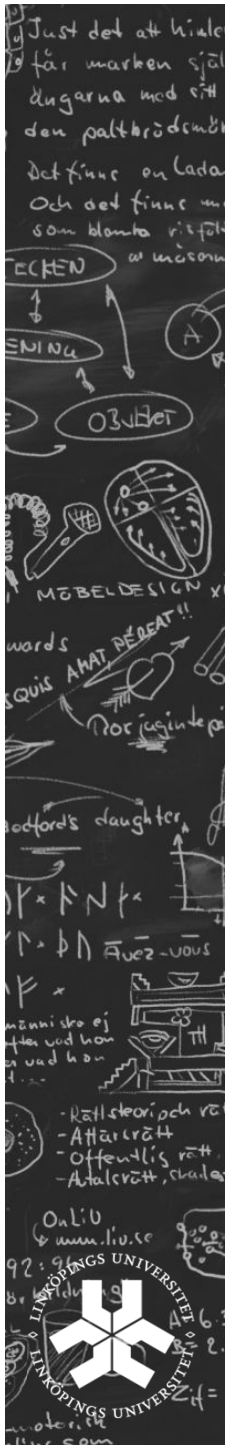
ICT production vs. usage

Comparison of phases in Desktop PCs

Production in China
consumes 2.4 GJ



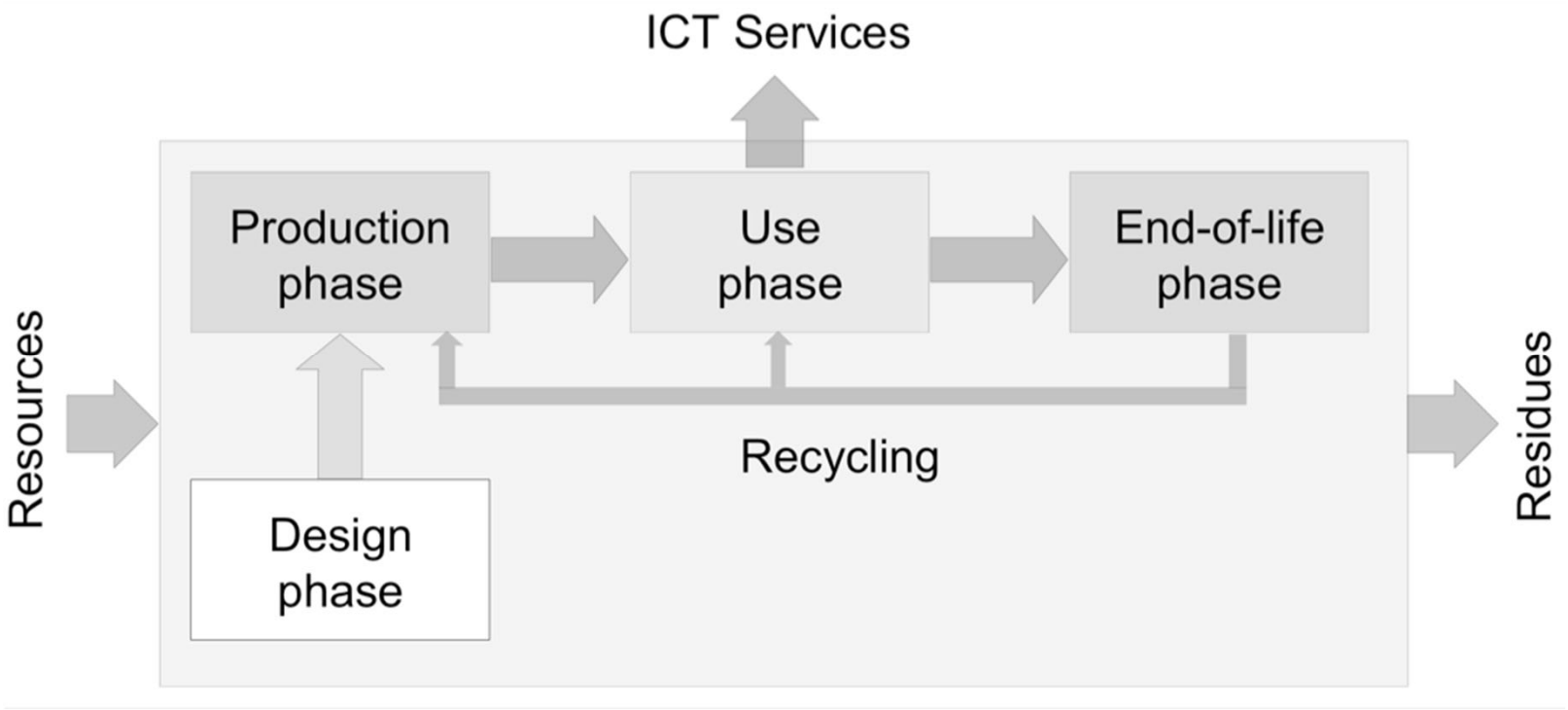
One year usage
consumes 0.8 GJ



How do we make choices?

- Usage phase offsets production after 3 years
  - This increases to 6 years if other environmental aspects are aggregated
  - Dependent on electricity supply mix
- Length of usage phase is a very relevant parameter
  - Short software innovation cycles with increasing hardware requirements are ecologically disastrous
  - Trade-off: use length extension vs. reduced consumption of new devices
- This can be applied to anything
  - even drinking coffee!
  - https://link.springer.com/article/10.1007%2Fs11367-018-1575-0 (Jan 2019)

Holistic approach: Life-Cycle of ICT



Lorenz M. Hilty. Information Technology and Sustainability: Essays on the Relationship between Information Technology and Sustainable Development, Books on Demand, 2008 ISBN: 978-3837019704

What is e-Waste?

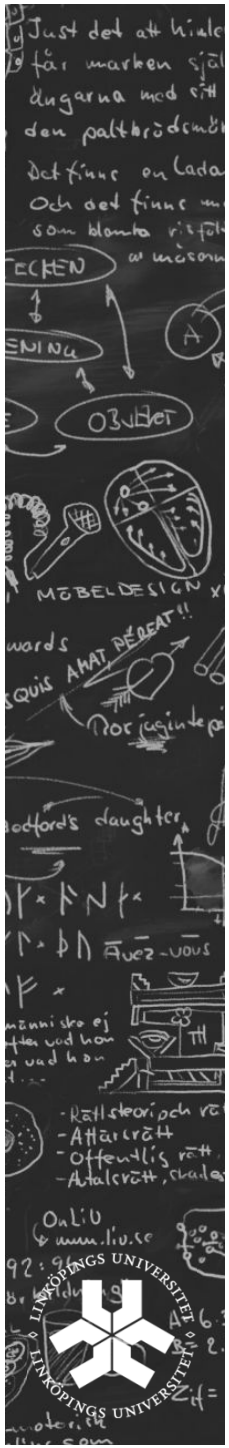
- Waste from electrical and electronic equipment
- e-Waste has become a serious problem
  - Total annual global volume is over 50 million tonnes (2019)
  - Treatment is a challenge, recycling is the key
- Recycling metals can save up 20-25% of production costs

https://ewastemonitor.info/the-global-e-waste-monitor-2024/

How to treat e-Waste?

- Informal recycling
  - Informal industry in emerging economies
  - Health and environmental impacts not considered
  - No or poor safety measures while manipulation
  - High levels of contaminants in the activity areas
    - Air, bottom ash, dust, soil, waters...

Pictures by courtesy of Technology and Society Lab, Empa Materials Science and Technology, Switzerland



Is there anything we can do about it?

- Some 80% of the pollution and 90% of the manufacturing costs associated with EEE are the result of decisions made at the product design stage

Circular Economy report August 2019

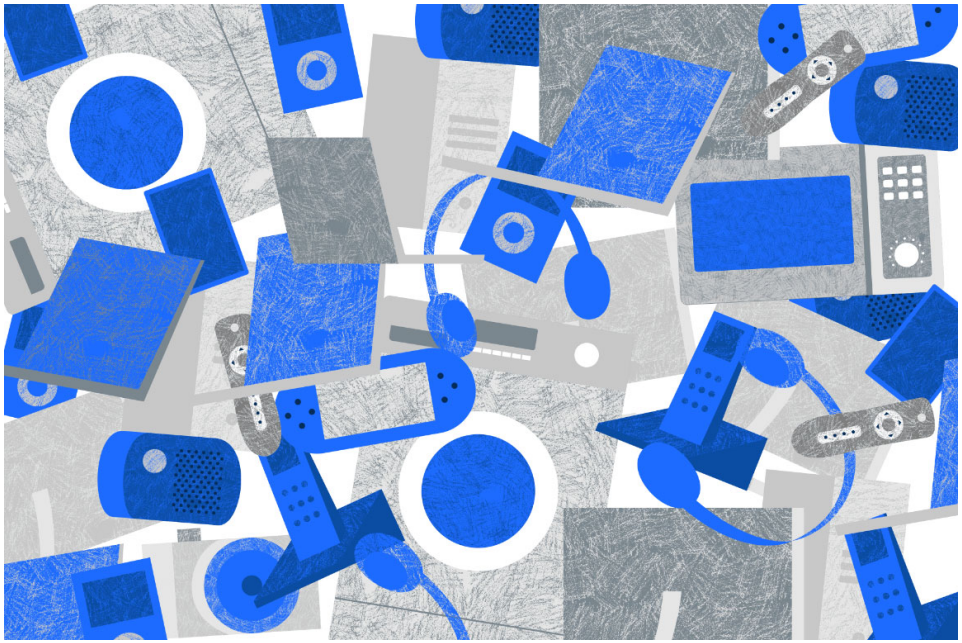
- https://www.impel.eu/en/projects/implementation-of-the-weee-directive

- 16 Jan 2025:

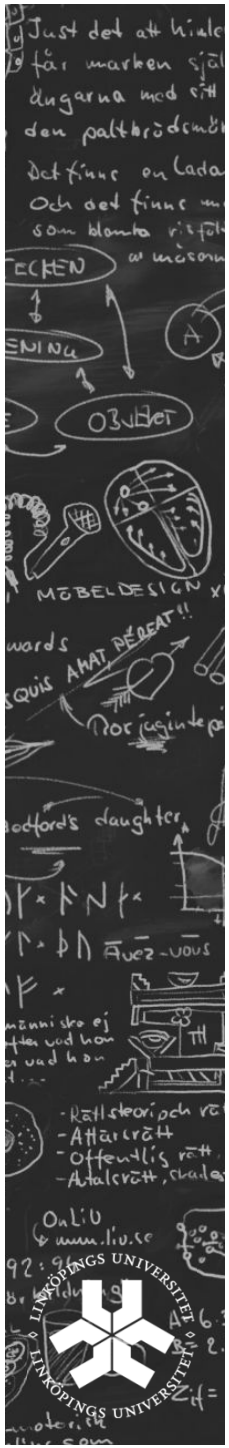
https://www.sverigesradio.se/artikel/tullen-rekordbeslag-av-export-med-miljofarlig-avfall

Good news!

- End of life electronics management is possible!

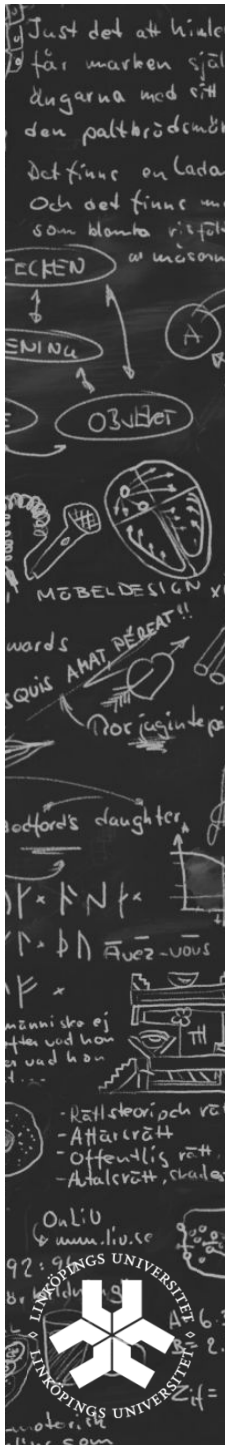


https://www.europarl.europa.eu/topics/en/article/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic



Terminology

- Introduction to sustainability
- Life-Cycle of ICT products
- **Eco-labelling and standards**



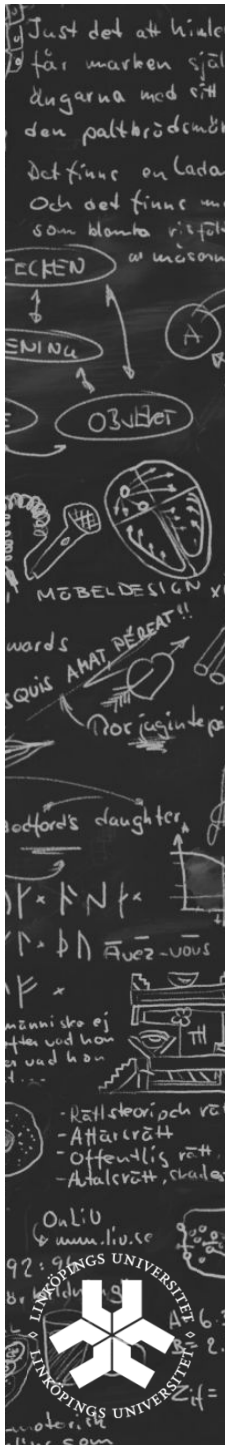
ENERGY STAR

- Set of **energy** performance specifications that qualified products must fulfill

"If every home office product purchased in the United States this year met ENERGY STAR requirements, we would:

- *Save more than $100 million in annual energy costs*
- *Prevent 1.4 billion pounds of greenhouse gases, equivalent to emissions from 125,000 cars*
- *Save more than 900 million kWh of electricity."*

http://www.energystar.gov, visited 2010



RoHS - EU Directive 2002/95/EC

- Restriction of use of certain Hazardous Substances (RoHS)
  - In electrical and electronic equipment
  - To protect human health and environment
  - For products put on the market since 1st July 2006

- Restricted substances
  - Lead
  - Mercury
  - Cadmium
  - Hexavalent chromium
  - Polybrominated biphenyls (PBB)
  - Polybrominated diphenyl ethers (PBDE)

http://ec.europa.eu/environment/waste/rohs_eee/index_en.htm

CSRD – Corporate Sustainability Reporting Directive - kommer att ställa större och mer omfattande krav på företags hållbarhetsrapportering.

DELA

Foto: Suriyo Munkaew / Mostphotos

Boka

12 december 2023

Status: **Lediga platser**

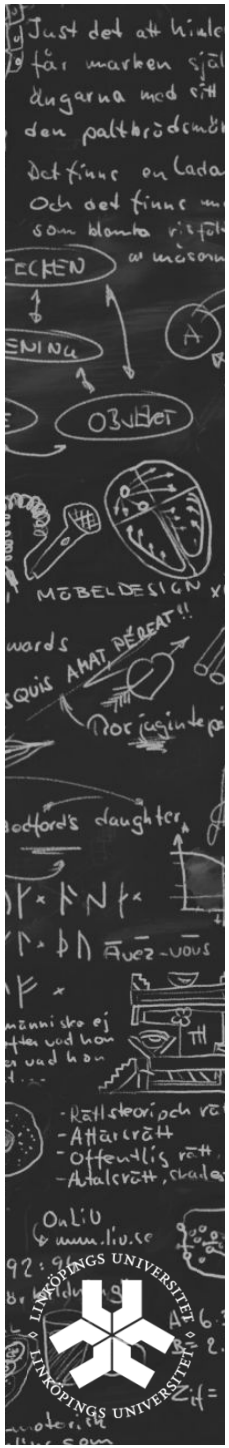
Antal dagar: **1 dagar**

Medlemspris: **2700 kr**

Icke medlemspris: **3375 kr**

Priserna är exklusive moms.

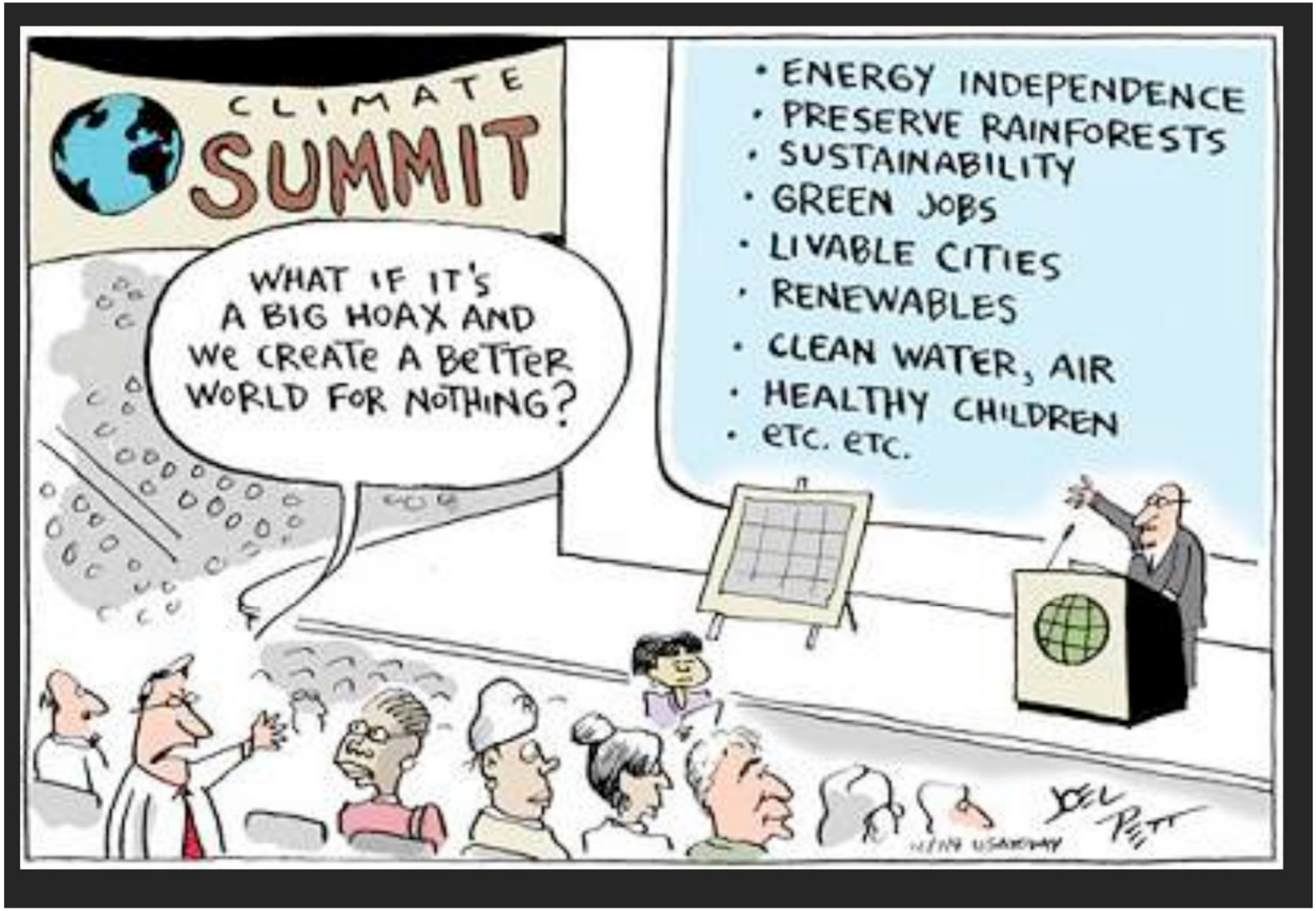
Boka



EPEAT / IEEE P1680

- Global registry of electronic products
  - Covers design, production, use, and disposal of products
  - Operation and criteria based on IEEE 1680 standards
  - 23 required criteria and 28 optional
- Products registered and declared by manufacturers
  - Independent verification of their claims
  - Fast product presence in the register
- Environmental product ranking
  - Bronze: Meets all 23 required criteria
  - Silver: Bronze plus 50% of the optional criteria
  - Gold: Bronze plus 75% of the optional criteria

http://www.epeat.net (Electronic Products Environmental Assessment Tool)


CLIMATE
SUMMIT
WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?
• ENERGY INDEPENDENCE
• PRESERVE RAINFORESTS
• SUSTAINABILITY
• GREEN JOBS
• LIVABLE CITIES
• RENEWABLES
• CLEAN WATER, AIR
• HEALTHY CHILDREN
• ETC. ETC.