How sustainable is information technology? Trends, challenges, and opportunities.

Illinois Sustainable Technology Center Webinar

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ERSAL develops mathematical models and decision support tools to quantify opportunities for reducing energy and resource use in:

- Manufacturing processes and supply chains;
- Product and material life-cycle systems; and
- Information technology systems.

Goal: Enable manufacturers and policy makers to identify robust technological, behavioral, and policy pathways toward more sustainable products and processes.

Some current projects:

- Supply chain energy efficiency potentials (National Science Foundation)
- Industrial cap and trade policy analysis (California Air Resources Board)
- Geo-temporal energy analysis of cloud computing (Google)
- Industrial energy and water efficient technology characterization (U.S. EPA)
- Student life-cycle audit program for small manufacturers (Murphy Society)
- Life-cycle evaluation of advanced manufacturing technologies (U.S. DOE)
How sustainable is information technology?

On the one hand ...
Electronics and appliance energy use is increasing.

MARCH 7, 2013

Heating and cooling no longer majority of U.S. home energy use

Energy consumption in homes by end uses
quadtrillion Btu and percent

<table>
<thead>
<tr>
<th>End Use</th>
<th>1993</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>10.01</td>
<td>10.18</td>
</tr>
<tr>
<td>Space Heating</td>
<td>24.0%</td>
<td>34.6%</td>
</tr>
<tr>
<td>Air Conditioning</td>
<td>18.3%</td>
<td>17.7%</td>
</tr>
<tr>
<td>Water Heating</td>
<td>4.6%</td>
<td>6.2%</td>
</tr>
<tr>
<td>Appliances, electronics, and lighting</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Amounts represent the energy consumption in occupied primary housing units.
Data center energy use is growing

Figure 1: Worldwide electricity use for data centers (2000, 2005, and 2010)

Some facts about electronics

• Our modern way of life requires lots of electronics!
  – 4.5 billion people using cell phones in 2014 (eMarketer 2014)
  – Over 300 million PCs shipped in 2014 worldwide (IDC 2015)
  – 150 million computers in U.S. homes (roughly 50/50 laptops desktops; nearly all have internet access) (U.S. DOE 2013)
  – Over 400 million rechargeable electronic devices in U.S. homes (cell phones, ipods, cameras, etc.) (U.S. DOE 2013)
  – Nearly 300 million televisions in U.S. homes (most homes have two, more homes with three than one!) (U.S. DOE 2013)
Some facts about electronics

- And they use lots of energy! (U.S. DOE 2014)
  - About 1/3 of home energy use is attributable to electronics and appliances (\(=1/3 \times 21\) quads = 7 quads)
  - About 1/5 of office energy use is attributable to electronics (\(1/5 \times 14\) quads = 3 quads)
  - Combined office and home = 10 quads = 1/10 of U.S. energy use
  - 10 quads = roughly equivalent to annual energy use of all U.S. passenger cars (light duty vehicles)
  - 10 quads = energy use by first 1 billion of the world's population when ranked by energy use
Standby power

http://www.ecomythsalliance.org/2012/12/the-dark-side-of-standby-electronics/
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  – About $1/3$ of home energy use is attributable to electronics and appliances ($=1/3 \times 21 \text{ quads} = 7 \text{ quads}$)
  – About $1/5$ of office energy use is attributable to electronics ($1/5 \times 14 \text{ quads} = 3 \text{ quads}$)
  – Combined office and home = 10 quads = $1/10$ of U.S. energy use
  – 10 quads = roughly equivalent to annual energy use of all U.S. passenger cars (light duty vehicles)
  – 10 quads = energy use by first 1 billion of the world's population when ranked by energy use
  – U.S standby losses = 1 quad = energy use by roughly the first 200 million of the world's population
  – 1 quad = 20 million light duty vehicles (passenger vehicles)
The 1.7 kg microchip

- Study considered the mass inputs of secondary fossil fuels and chemicals necessary to manufacture a 2 g microchip

- If supply chain and process solid waste generation were considered, the results would have been much higher!

Source: The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices

FIGURE 2. Summary input/output table for wafer fabrication

Source: The 1.7 Kilogram Microchip: Energy and Material Use in the Production of Semiconductor Devices
Importance of manufacturing impacts

15-inch MacBook Pro with Retina Display
Environmental Report

Model numbers
MGXA2, MGXC2

Date introduced
July 29, 2014

Greenhouse Gas Emissions for 15-inch MacBook Pro with Retina Display

- Production, 80%
- Recycling, 1%
- Transport, 4%
- Customer use, 15%

Total greenhouse gas emissions: 880 kg CO₂e

https://www.apple.com/environment/reports/
EU-25 total impacts during service life of PC and displays sold in 2005

http://www.ecocomputer.org/
“Of the e-waste in developed countries that is sent for recycling, 80% ends up being shipped (often illegally) to developing countries to be recycling by hundreds of thousands of informal workers.” International Labour Organization, 2012

Fig. 2. Export of e-waste (Lewis, 2011)

Recycling effectiveness depends on the system!

Example recycling of WEEE
Recovery of technology metals from circuit boards

Collection 10,000’s

Number of actors in Europe

Dismantling

1000’s

Preprocessing

100’s

Smelting & refining of technology metals (metallurgy)

Investment needs

Total efficiency is determined by weakest step in the chain
Make sure that critical fractions reach these plants

Example: 30% x 90% x 60% x 95% = 15%


Image courtesy of Christian Hagelueken, Umicore
How sustainable is information technology?

On the other hand ...
Component efficiency increases dramatically!

Computation per kWh doubles every 1.57 years.

Component efficiency increases dramatically!

Figure 7. Minimum Storage Energy Intensity for Selected Enterprise Hard Drives

Technical potential for U.S. data center energy savings

- Current (2008) demand scenario: 69.0
- Device reduction: servers: -12.7
- Improved server efficiency: -4.6
- Dynamic frequency/voltage scaling: -3.0
- Network port reduction & efficiency: -2.4
- Device reduction: storage: -1.5
- Improved storage efficiency: -1.0
- Reduced IT device demand: -25.1
- Improved cooling efficiency: -3.8
- Improved UPS efficiency: -1.4
- Improved transformer efficiency: -0.4
- Improved lighting efficiency: -0.4
- Efficient scenario: 12.8

**Total potential energy savings for IT devices:** 25.1 billion kWh

**Total potential energy savings for infrastructure systems:** 31.1 billion kWh

## Energy use by client

<table>
<thead>
<tr>
<th>Device unit electricity (kWh/year)</th>
<th>2006</th>
<th>2010</th>
<th>2012 (est)</th>
<th>2017 (est)</th>
<th>CAGR 2010-2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desktop PC</td>
<td>237</td>
<td>220</td>
<td>212</td>
<td>193</td>
<td>-1.8%</td>
</tr>
<tr>
<td>Laptop PC</td>
<td>72</td>
<td>63</td>
<td>61</td>
<td>56</td>
<td>-1.6%</td>
</tr>
<tr>
<td>LCD monitor</td>
<td>85</td>
<td>97</td>
<td>100</td>
<td>109</td>
<td>1.7%</td>
</tr>
<tr>
<td>Game console</td>
<td>36</td>
<td>135</td>
<td>149</td>
<td>190</td>
<td>5.0%</td>
</tr>
<tr>
<td>Set top box</td>
<td>131</td>
<td>135</td>
<td>136</td>
<td>136</td>
<td>0</td>
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<tr>
<td>TV set</td>
<td>249</td>
<td>183</td>
<td>173</td>
<td>152</td>
<td>-3%</td>
</tr>
<tr>
<td>DVD / Blu-ray player</td>
<td>36</td>
<td>28</td>
<td>25</td>
<td>18</td>
<td>-6%</td>
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<tr>
<td>AV receiver</td>
<td>–</td>
<td>65</td>
<td>65</td>
<td>65</td>
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<td>Tablet</td>
<td>–</td>
<td>–</td>
<td>12</td>
<td>12</td>
<td>0</td>
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<tr>
<td>Smartphone</td>
<td>–</td>
<td>–</td>
<td>3</td>
<td>3</td>
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U.S. GHG footprint of media consumption

California Imposes Rule for Efficiency on Some TVs

By CLIFFORD KRAUSS
Published: November 16, 2009

Recognizing that giant new flat-panel televisions have become major power guzzlers, California on Wednesday became the first state to impose energy efficiency standards on them.

The California Energy Commission voted unanimously to apply the standard, which would take effect in 2011. There is no federal energy-efficiency standard for televisions.

California, which often leads the nation in taking action on environmental issues, banned power-hungry refrigerators and air-conditioners in the 1970s and has enforced strong energy codes on residential and commercial buildings for decades. But the new regulation may prove the most challenging to consumers’ tastes.

The rule does not cover televisions currently in use or for sale. But it would require that most television sets sold in California consume 33 percent less electricity by 2011 and 49 percent less by 2013. The standards would apply to televisions with a screen size of up to 58 inches.
Televisions Represent Significant Energy Use

The residential energy consumption due to televisions rapidly increased from 3-4% in 1990s to 8-10% in 2008. Television energy will grow up to 18% by 2023 without regulations. The projected growth does not include the residential energy use by cable boxes, DVD players, internet boxes, Blue Ray, game consoles etc.

Technically Feasible Standards

*Consumers can expect to save between $50 - $250 over the life of their TV

*A 50 inch plasma can consume as little as 307 kWh/yr and as much as 903 kWh/yr

Projected success of ENERGY STAR product labels

Figure 1. Carbon Savings for EPA ENERGY STAR Labeled Products (1993-2015)

We need better knowledge to answer this question
- Understanding energy implications (both positive and negative) is critical for sustainability decisions
- Complexity precludes easy answers

Some barriers to generating this knowledge:
- Studies are difficult to compare:
  - Differences in analysis boundaries and scales
  - Non-transparent approaches
  - Rapidly changing technologies and behavior

The Cloud Energy and Emissions Research (CLEER) Model
- A public use model that:
  - Considers all major end uses of energy
  - Documents equations and data sources
  - Allows users to change or update inputs
  - Is open for critique by the research community
A first step toward knowledge aggregation and generation, research collaboration, and open scientific development
Cloud Energy and Emissions Research Model

US - Email Scenario

Present day Data Center 1
Cloud Data Center 1

Edit Data Center

- Data Center type: Server Closet
- Region: US Average
- Carbon intensity of electricity source (kg CO2e/kWh): 0.67
- Primary Energy (MJ/kWh): 13.8
- Number of Volume Servers: 1016277
- Number of Mid-Range Servers: 0

An open model where you can change the inputs

http://energy-model.lbl.gov/
Cloud-based business software case study

Figure 3: Estimated number of U.S. business software users by: (a) firm size and (b) occupation.

Figure 4: Estimated software hosting characteristics by: (a) application and (b) firm size.
Potential for Server Reduction?

Client Device Characteristics

**Figure 6:** Estimated numbers and types of client IT devices used for business software by U.S. workers
Cloud-based software could reduce present day energy use by around 85%.

Technical potential for energy savings equates to ~23 billion kWh/yr, or the total annual electricity use of Los Angeles.

How Uncertain Are the Results?

Are these savings robust?
Present day inefficiencies are pervasive, especially at small firms = large savings
Data uncertainties don’t alter this general conclusion

Data centers in New York State (2014)

Total for all space types = 7.6 million MWh

- Server closets and rooms
- Localized
- Mid-tier
- Enterprise

- Cooling
- Lighting
- UPS
- Transformers
- Network
- Storage
- Servers
Technical potential with efficient technology trends (assumed demand growth of 20%/year)

Business as Usual 2014-2020 by Component

Million megawatt-hours (MWh)

-40%


- Cooling
- Lighting
- UPS
- Transformers
- Network
- Storage
- Servers

NORTHWESTERN UNIVERSITY
Projections with institutional technology trends (assumed demand growth of 20%/year)

Business as Usual 2014-2020 by Component

<table>
<thead>
<tr>
<th>Year</th>
<th>Cooling</th>
<th>Lighting</th>
<th>UPS</th>
<th>Transformers</th>
<th>Network</th>
<th>Storage</th>
<th>Servers</th>
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<td>2020</td>
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</table>

+47%
United States water use

This publication is available online at: http://pubs.usgs.gov/fs/2009/3098/

2005 withdrawals by category, in million gallons per day. States are arranged geographically.
Intelligent Efficiency Example

- Smart components
- Networked
- Adaptive and anticipatory
- Computer or user controlled

Input: water
Output: crop yield

http://www.smart-farms.net/
The “enabling” effect of information technology

PG&E SmartMeter

Power electronics for vehicles and renewables

Caterpillar AccuGrade

Dematerialization

Courtesy of PG&E

Courtesy of Caterpillar

Courtesy of Mitsubishi

Courtesy of Apple
Taking Stock: Special Issue on “Environmental Applications of Information and Communications Technology”

• Premier journal in the areas of analysis, trends, and critical assessments of innovations and technologies related to sustainability

• Deep historical ties to the research community on ICT and environment
  – “E-Commerce, the Internet, and the Environment,” Volume 6, Number 2

• Ranked in top 1/3 of environmental science journals

• Special issue sponsor: Computer Sciences Corporation’s Leading Edge Forum
Net Productivity Benefits of Semiconductors

“Semiconductors and Information Technologies: The Power of Productivity”
John “Skip” Laitner, American Council for an Energy Efficient Economy

Future Electricity Scenarios for the United States

Reference case = U.S.DOE Energy Information Administration projections
How sustainable is information technology?

We must consider net effects!
Environmental Balance of IT Affected by Many Factors

- IT device production system characteristics and footprint (where, how, and with what are devices made?)
- IT device usage and services provided (which devices, for how long, and to what purposes?)
- How many IT devices are required as population and affluence grow, new applications emerge, and behaviors change?
- How are physical service systems changed and displaced? (e.g., digital news, video, mail)
- Spatial characteristics (energy mix, local environment, etc.)
- Technological change over time (IT devices, energy systems, production characteristics ... only constant is change!)
- Pace of change in technologies and behavior >> pace of research
- And many more factors ...
Many Research Barriers!

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Research barriers
- Chronic lack of data
- Disparate data sets
- Disparate models
- Temporal issues
- Spatial issues
- Lack of community, coordination, and data sharing
Which characteristics matter? Metrics needed!

Capgemini Opens Merlin Data Center in UK
With PUE of 1.1

October 2010

Google Embraces Free Cooling in Belgian Data Center

GreenBiz  July 2009

Telecommunications giant AT&T will install Bloom Energy fuel cells at 11 sites in California

July 2011

Virtualization Saves Microsoft Customers Nearly a Half-Million Dollars Per Year

February 2009

Zero Waste: The Next Step for Data Center Sustainability

Environmental Leader  April 2011

<table>
<thead>
<tr>
<th>Company</th>
<th>Clean Energy Index</th>
<th>Coal Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Akamai</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Amazon</td>
<td>26.8%</td>
<td>28.5%</td>
</tr>
<tr>
<td>Apple</td>
<td>6.7%</td>
<td>54.5%</td>
</tr>
<tr>
<td>Facebook</td>
<td>13.8%</td>
<td>53.2%</td>
</tr>
<tr>
<td>Google</td>
<td>36.4%</td>
<td>34.7%</td>
</tr>
<tr>
<td>HP</td>
<td>9.9%</td>
<td>49.4%</td>
</tr>
<tr>
<td>IBM</td>
<td>10.9%</td>
<td>51.6%</td>
</tr>
<tr>
<td>Microsoft</td>
<td>25%</td>
<td>34.1%</td>
</tr>
<tr>
<td>Twitter</td>
<td>21%</td>
<td>42.5%</td>
</tr>
<tr>
<td>Yahoo!</td>
<td>55.9%</td>
<td>18.3%</td>
</tr>
</tbody>
</table>
How Important is Hardware vs. Operations?

Broad Range of Performance

Consideration of net effects: Case study of streaming video

The energy and greenhouse-gas implications of internet video streaming in the United States

Arman Shehabi et al 2014 Environ. Res. Lett. 9 054007
doi:10.1088/1748-9326/9/5/054007
17.2 billion hours of viewing in 2011

- Streaming (Netflix) 25%
- Store Rented DVD 42%
- Mail Rented DVD (Netflix) 20%
- Streaming (other) 13%

Figure 2 from Arman Shehabi et al
2014 Environ. Res. Lett. 9 054007
Systems model for DVD viewing

- DVD Manufacture: DVD, DVD Case
- Shipping: Freight Shipping
- Storefront/Warehouse: Retail Case, Rental Paper Sleeve
- Delivery: Personal Vehicle, Postal Delivery
- Playback: DVD player, Game Console, Desktop Computer
- Viewing: Television, Flat Panel Monitor, Laptop Computer
Systems model for streaming video
Results per viewing hour

Primary energy use by viewing method

- DVD manufacture (embodied)
- DVD transport (shipping)
- DVD transport (consumer)
- Data center IT (embodied)
- Data center operation
- Data transmission (embodied)
- Data transmission
- Client devices (embodied)

CO₂(e) emissions by viewing method

- Streaming
- Rented
- Purchased
- Mail
- Rented
- Purchased
- Store
- Rented
- Purchased

kg of CO₂(e) emissions per viewing hour
Total annual results

2011 energy use for U.S. streaming & DVD viewing

- 2011 Streaming (3.2B hours): 25 PJ
- 2011 DVDs (17.2B hours): 167 PJ
- 100% Streaming (20.4 B hours): 162 PJ

2011 CO₂(e) emissions from U.S. streaming & DVD viewing

- 2011 Streaming (3.2B hours): 1.3 billion kg
- 2011 DVDs (17.2B hours): 9.2 billion kg
- 100% Streaming (20.4 B hours): 8.6 billion kg
Scenario analysis

- Total Primary Energy (MJ/hour)
- Data Transmission Energy (kWh/GB)

- Current streaming rate (2.33 Mbps)
- High streaming rate (20 Mbps)
- Typical DVD Player, Typical Transport
- Typical DVD player, Short Transport
- EnergyStar DVD player, Typical Transport
- EnergyStar DVD player, Short Transport
Thank You!

Questions?