UNIVERSITEIT GENT

FACULTY OF ENGINEERING AND ARCHITECTURE

Power-saving strategies for optical grids/clouds

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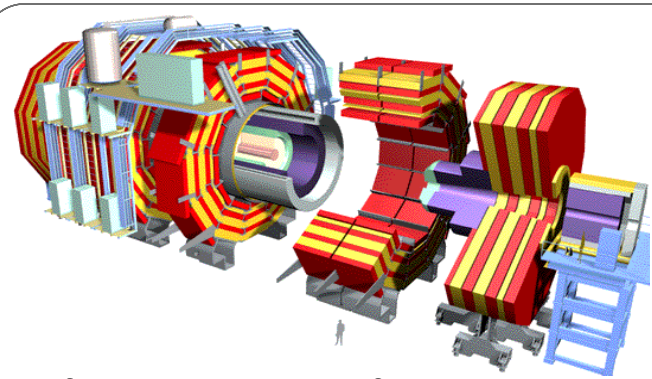
iMinds FUTURE INTERNET DEPT.

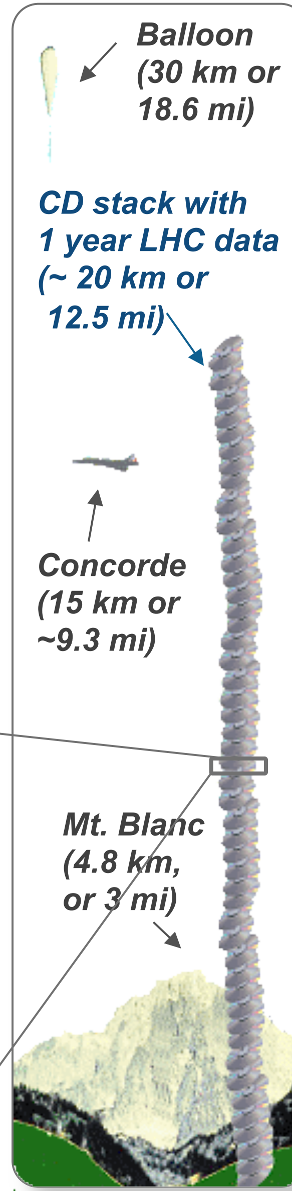
INTEC

Why optical grids/clouds? (1)

- eScience:
  - By 2015 it is estimated that **particle physicists** will require exabytes (10^{18}) of storage and **petaflops** (10^{15}) per second of computation
  - CERN's LHC Computing Grid (LGC), when fully operational will generate **15 petabytes** annually (that's ~2Gbit/s)



LHC = Large Hadron Collidor: particle accellerator



Why optical grids/clouds? (2)

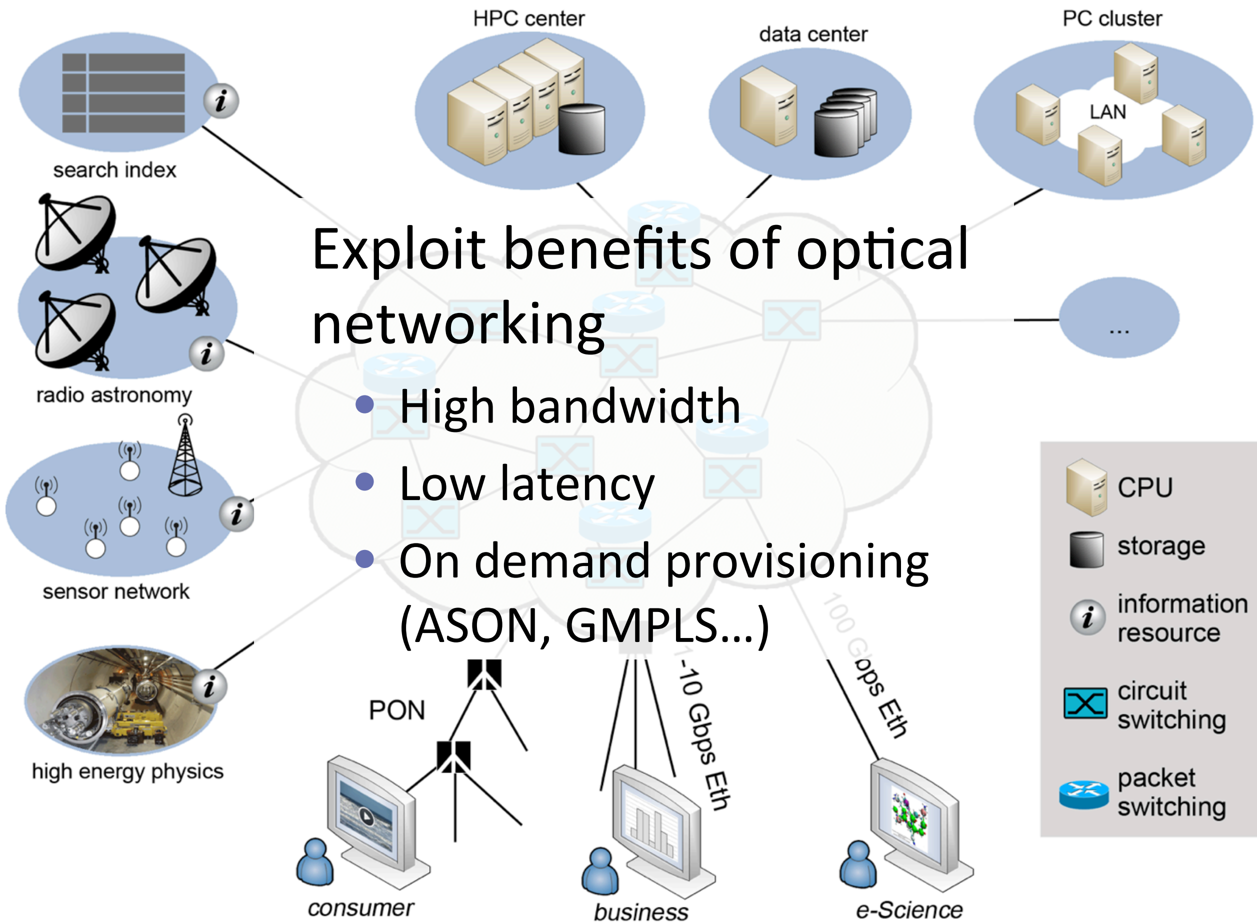
- Consumer service:
  - Eg. **video editing**: 2Mpx/frame for HDTV, suppose effect requires 10 flops/px/frame, then evaluating 10 options for 10s clip is **50 Gflops** (today's high performance PC: <5 Gflops/s)

Online gaming:
e.g. Final Fantasy XI: 1.500.000 gamers

*Virtual reality: rendering of 3*10^8 polygons/s → 10^4 GFlops*

Multimedia editing

Optical grids/clouds



Exploit benefits of optical networking

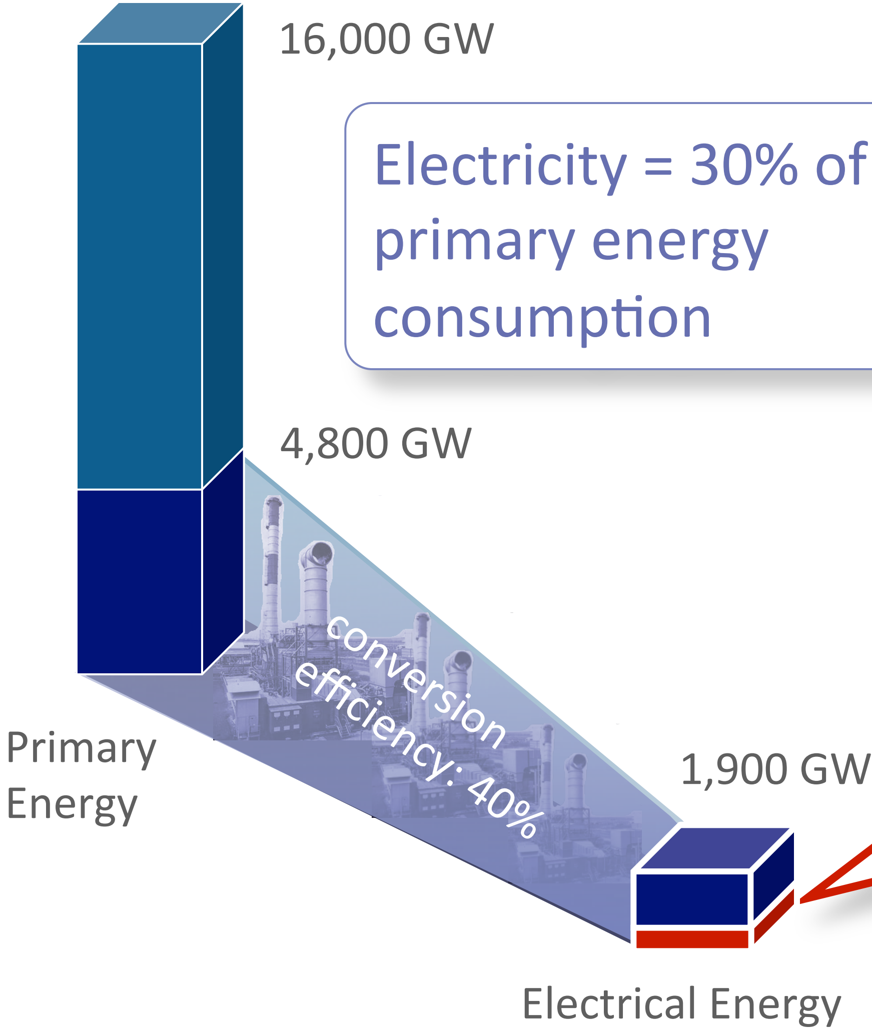
- High bandwidth
- Low latency
- On demand provisioning (ASON, GMPLS…)

C. Develder, et al., *"Optical networks for grid and cloud computing applications"*, Proc. IEEE, Vol. 100, No. 5, May 2012, pp. 1149-1167.

Agenda

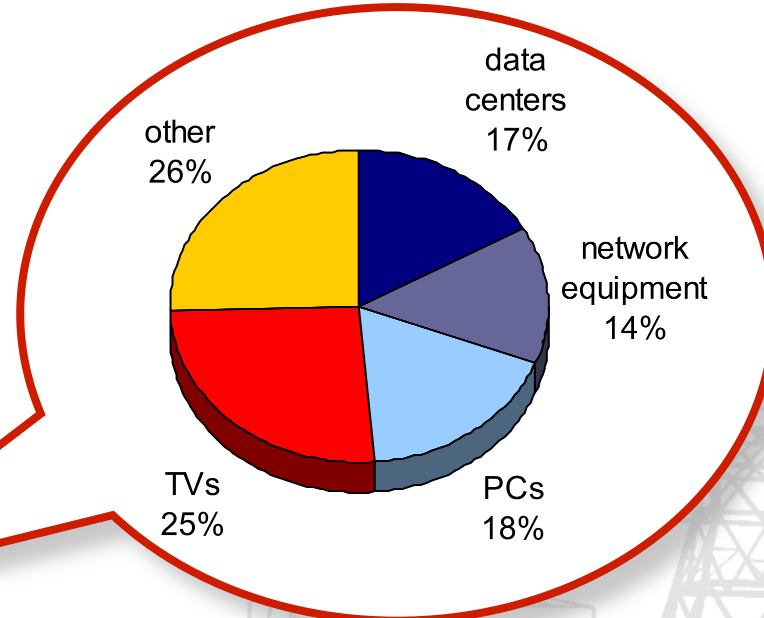
1. Energy consumption in ICT?
2. Improving energy efficiency
   - Energy efficient routing
   - Energy efficient scheduling
   - Energy efficient routing + scheduling
3. Maximizing green energy usage
4. Wrap-up

Power consumption 2007



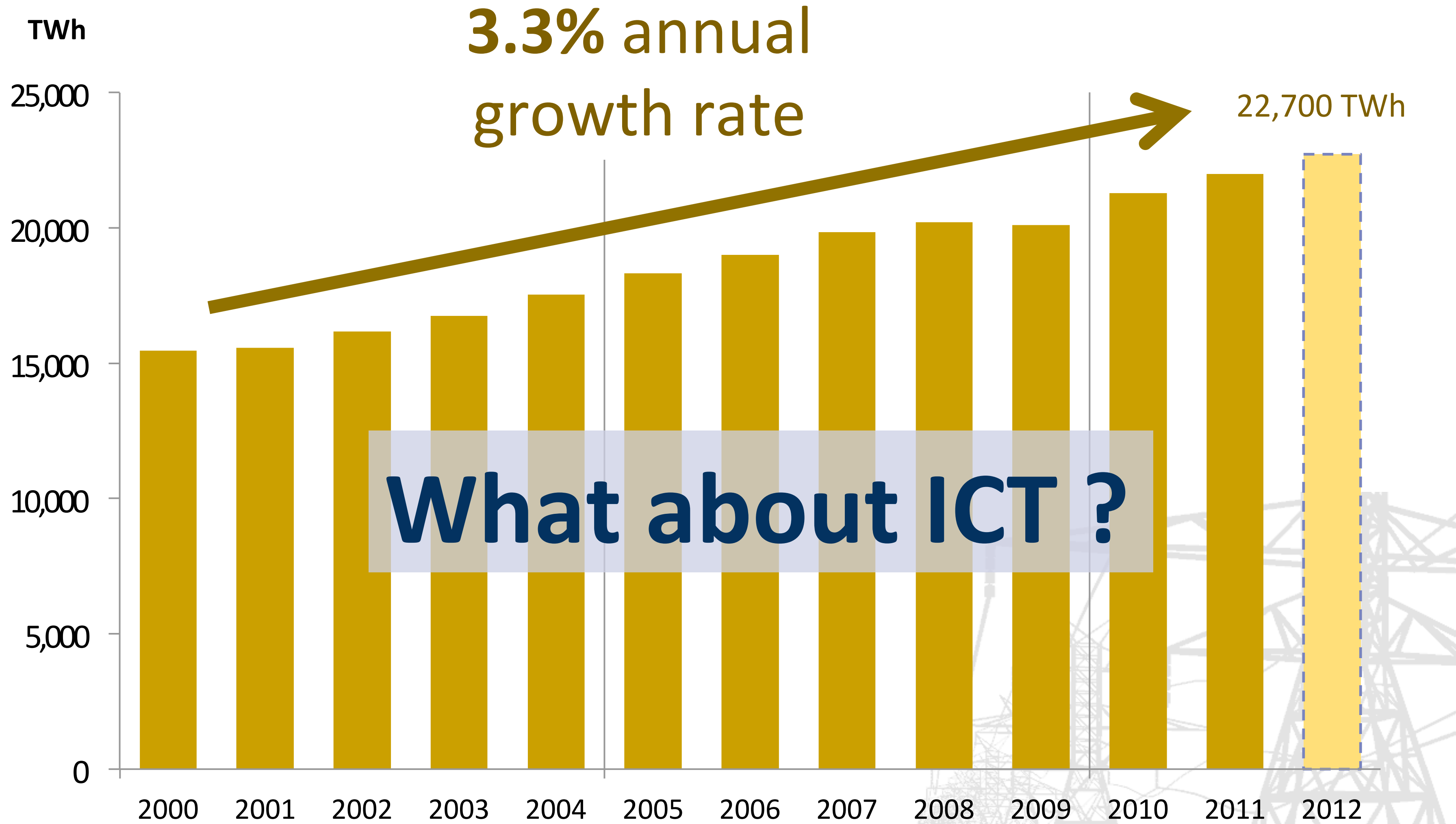
Electricity = 30% of primary energy consumption

ICT = 156 GW
>8% of total electricity consumption*, equaling 2.5% of primary energy



*: operational energy only, excl. manufacturing (manufacturing energy ~ energy during use phase!)

Electricity production rates worldwide



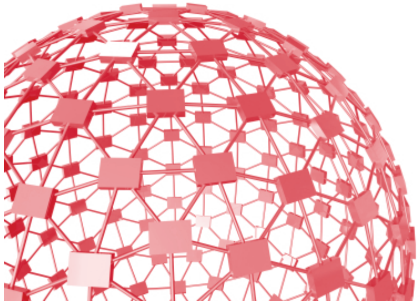
Data: based on http://yearbook.enerdata.net

ICT: what do we mean?

- ICT = Information & Communication Technologies

Computers

\+

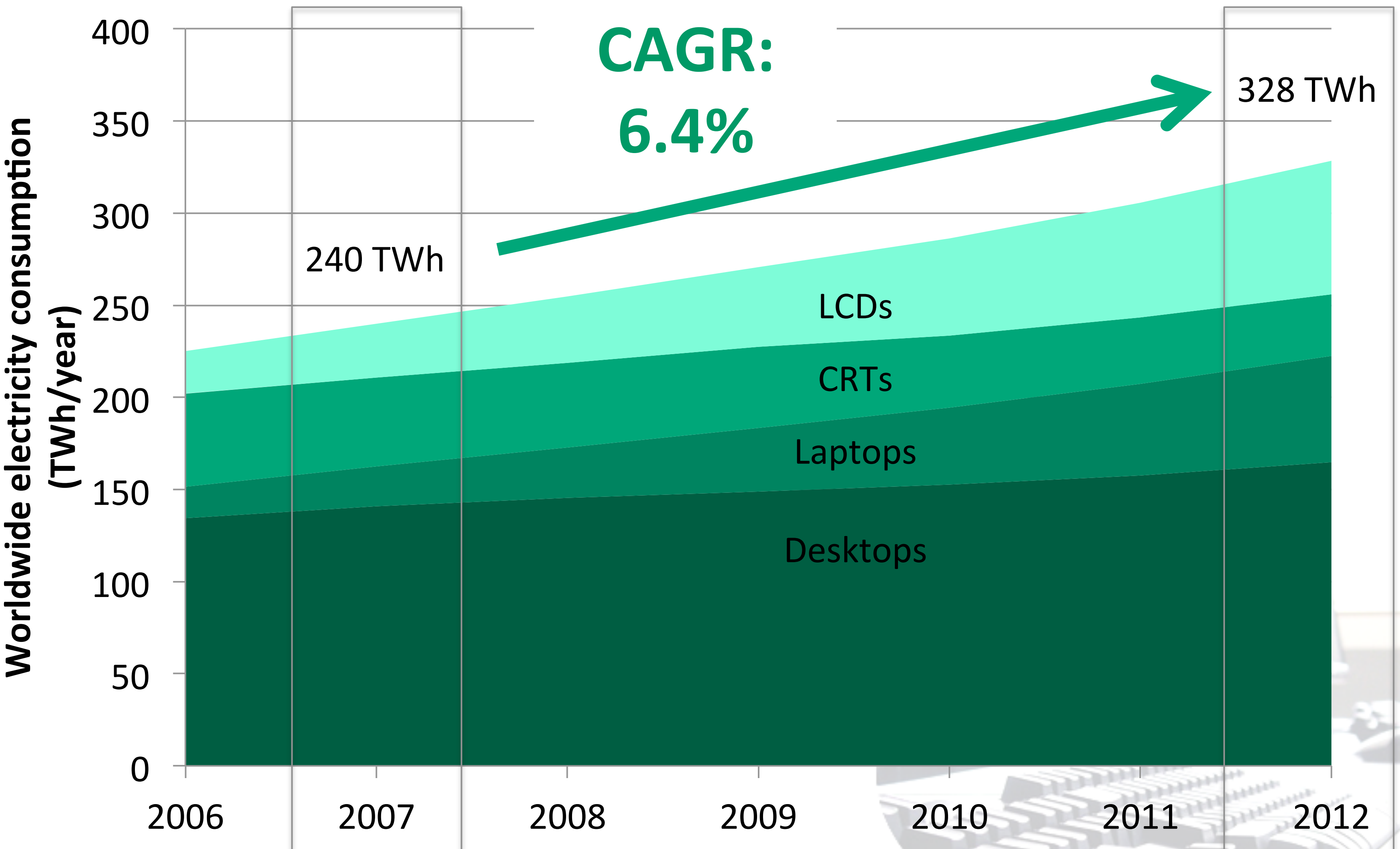


Communication network

\+

Data centers

Footprint of computers



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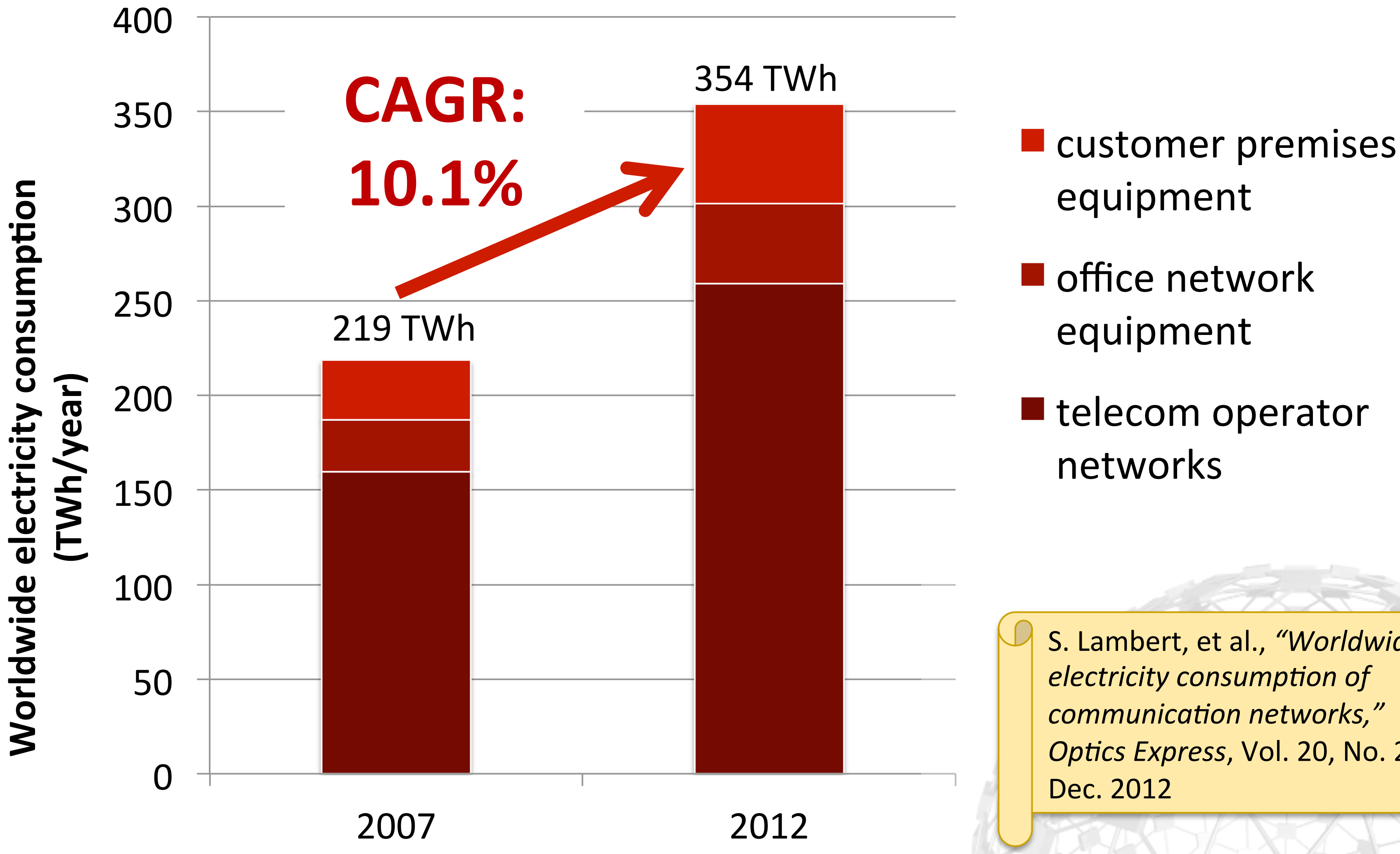
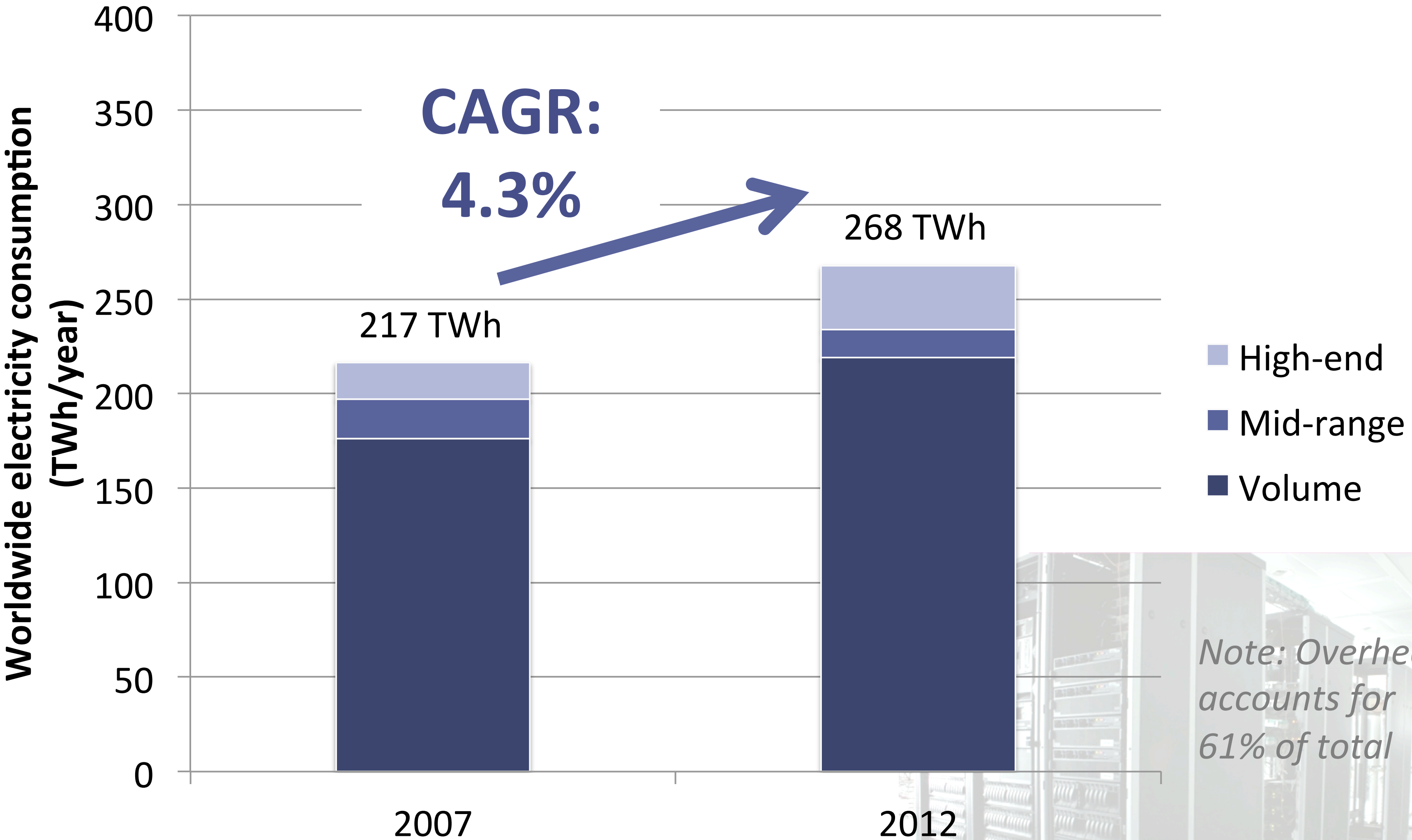
C. Develder, "Power-saving strategies for optical grids/clouds", Entretiens Jacques Cartier, Lyon, 19-20 Nov. 2012

Footprint of communication networks



S. Lambert, et al., *"Worldwide electricity consumption of communication networks,"* *Optics Express*, Vol. 20, No. 26, Dec. 2012

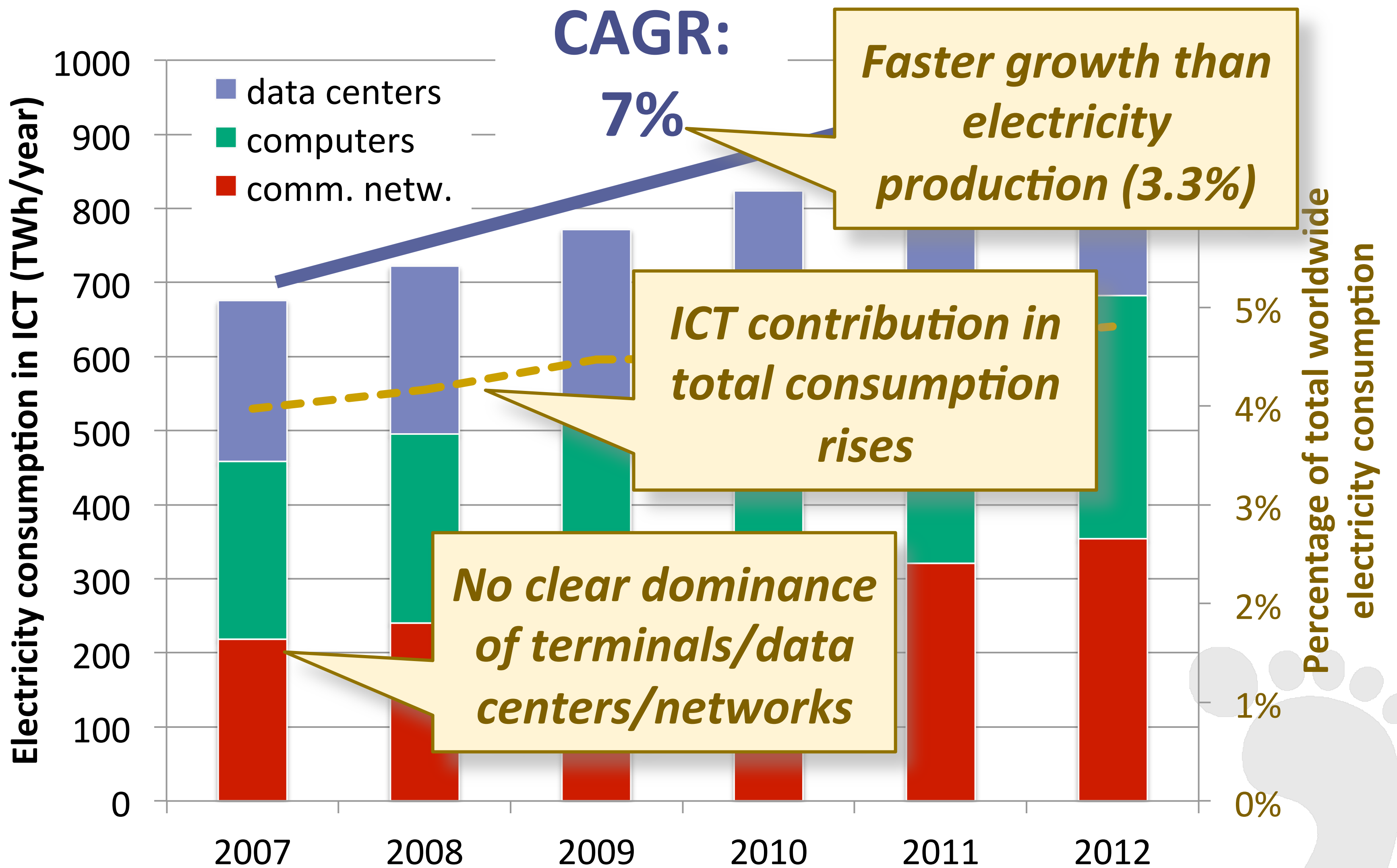
Footprint of data centers



Note: Overhead accounts for 61% of total

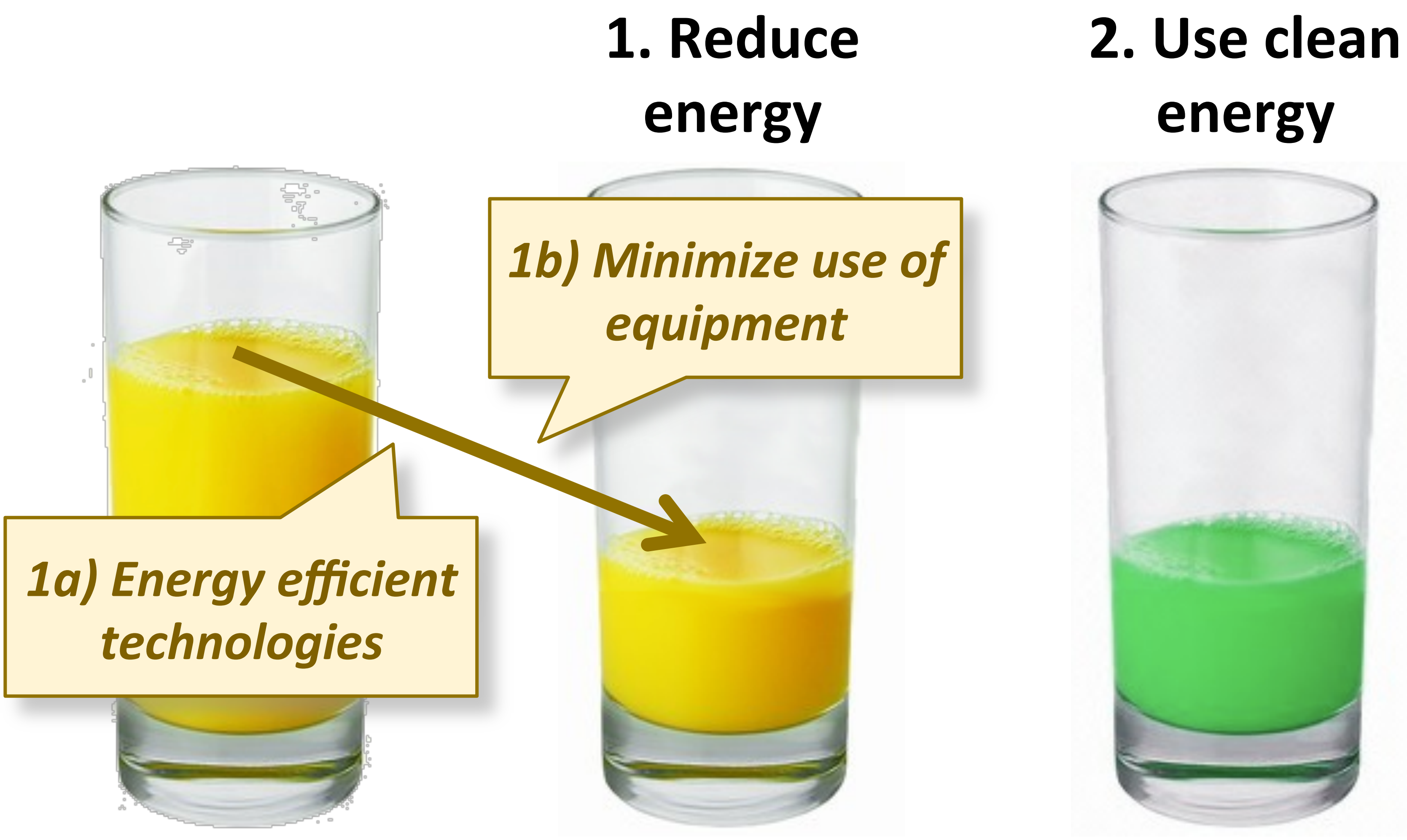
C. Develder, "Power-saving strategies for optical grids/clouds", Entretiens Jacques Cartier, Lyon, 19-20 Nov. 2012

Joint ICT footprint

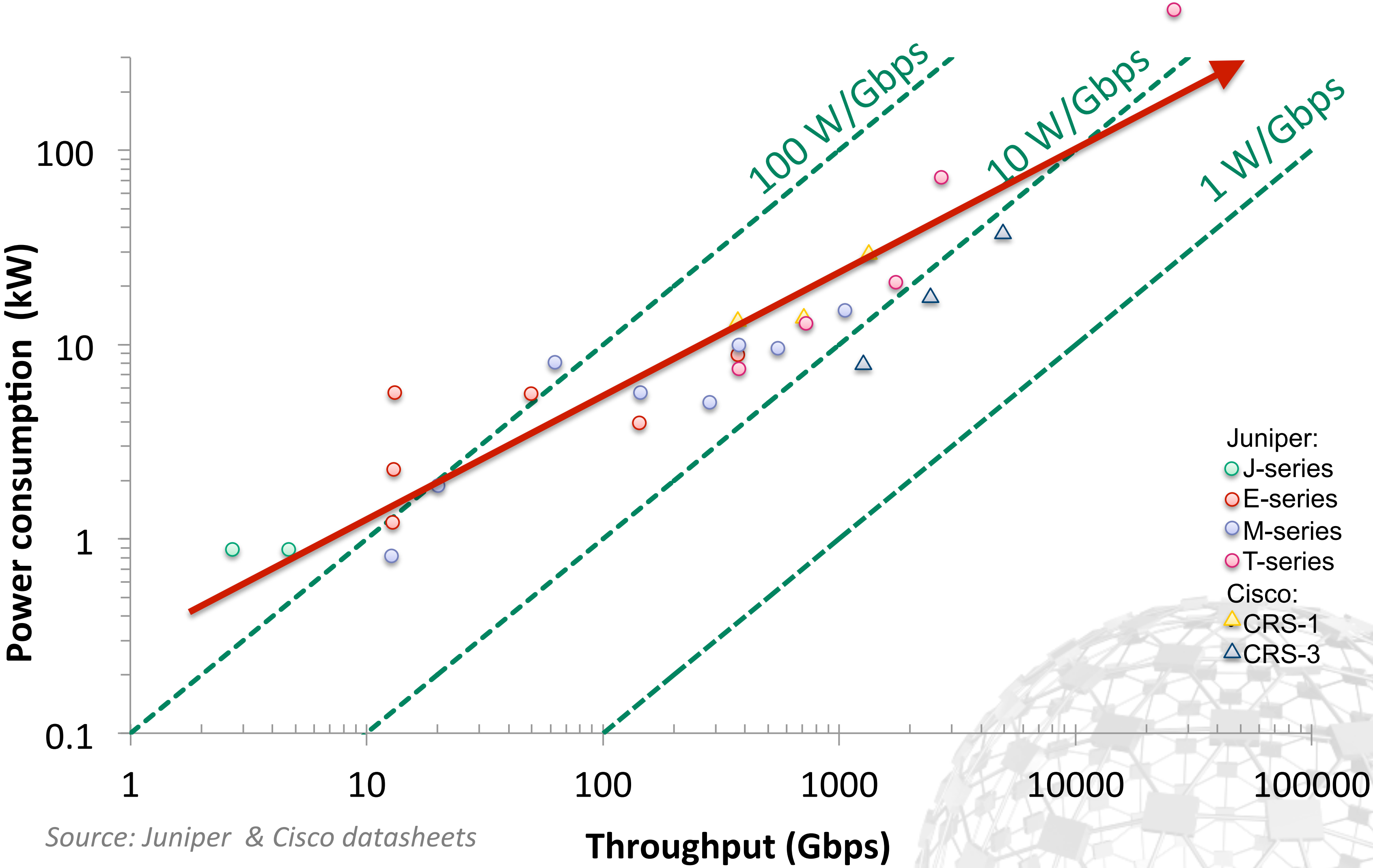


C. Develder, "Power-saving strategies for optical grids/clouds", Entretiens Jacques Cartier, Lyon, 19-20 Nov. 2012

Green ICT – Requires two high-level approaches

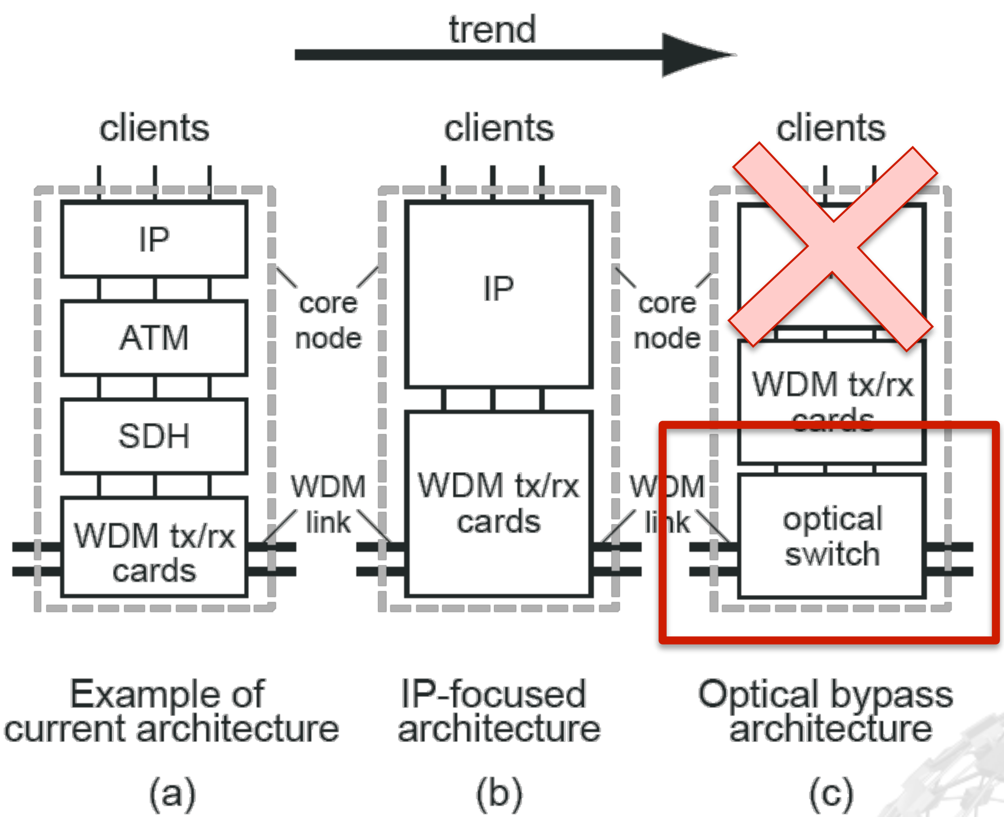


Energy efficient technology: Routers



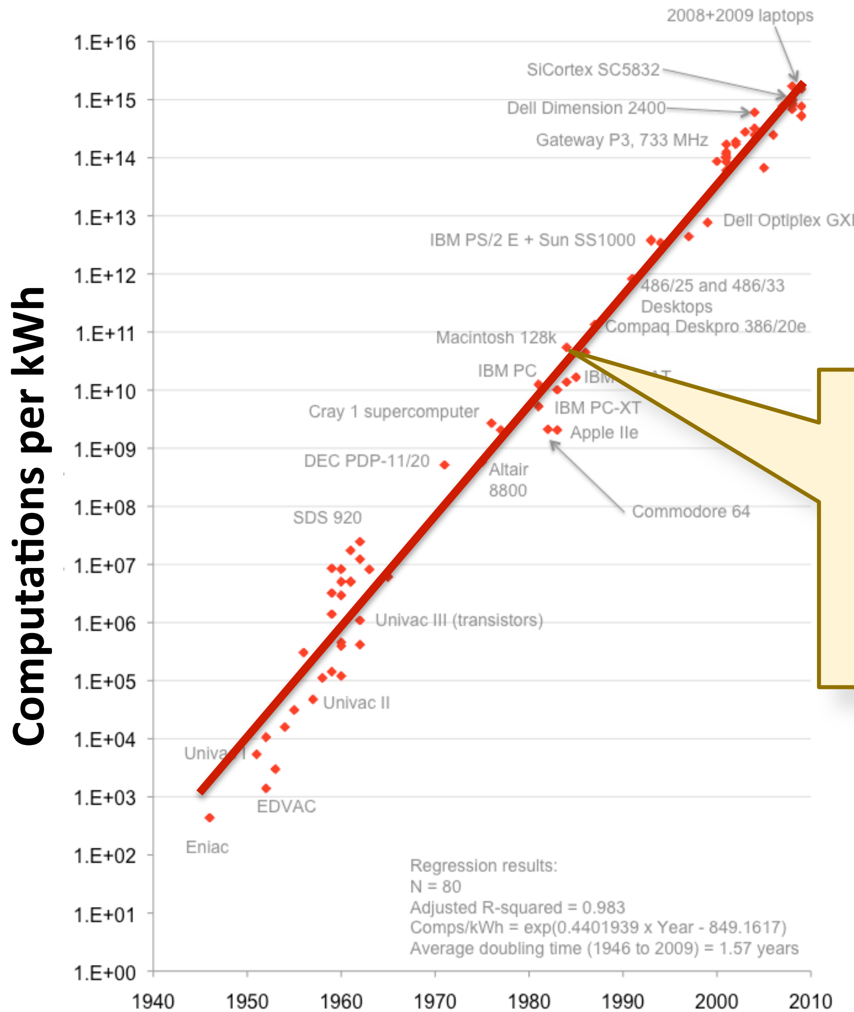
Source: Juniper & Cisco datasheets

Energy efficient technologies: Core networks



W. Vereecken et.al., *"Power consumption in telecommunication networks: Overview and reduction strategies"*, IEEE Commun. Mag., vol. 49, no. 6, Jun. 2011, pp. 62-69

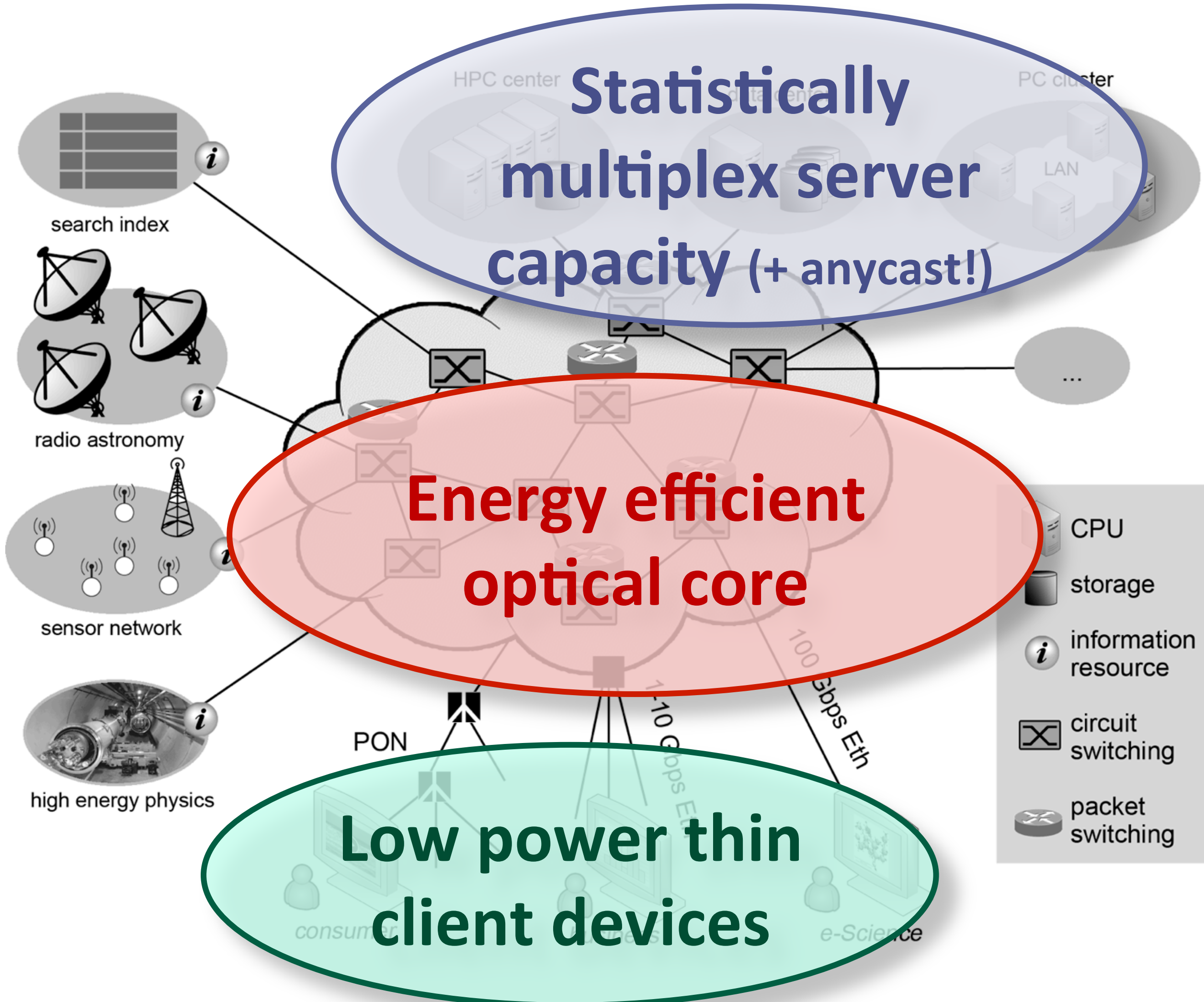
Energy efficient technologies: Data Centers



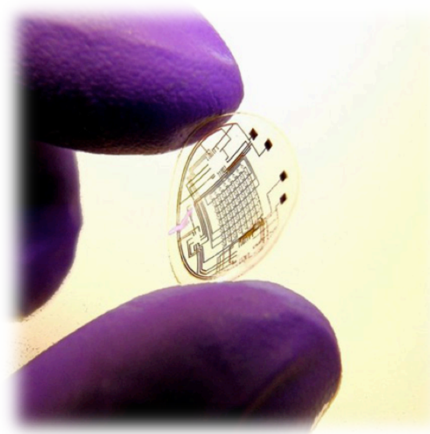
"Koomey's law": Computational energy-efficiency doubles every 1.6 years

Koomey, et.al., *"Implications of Historical Trends in The Electrical Efficiency of Computing"*, IEEE Annals of the History of Computing, vol. 33, no. 3, Mar. 2011

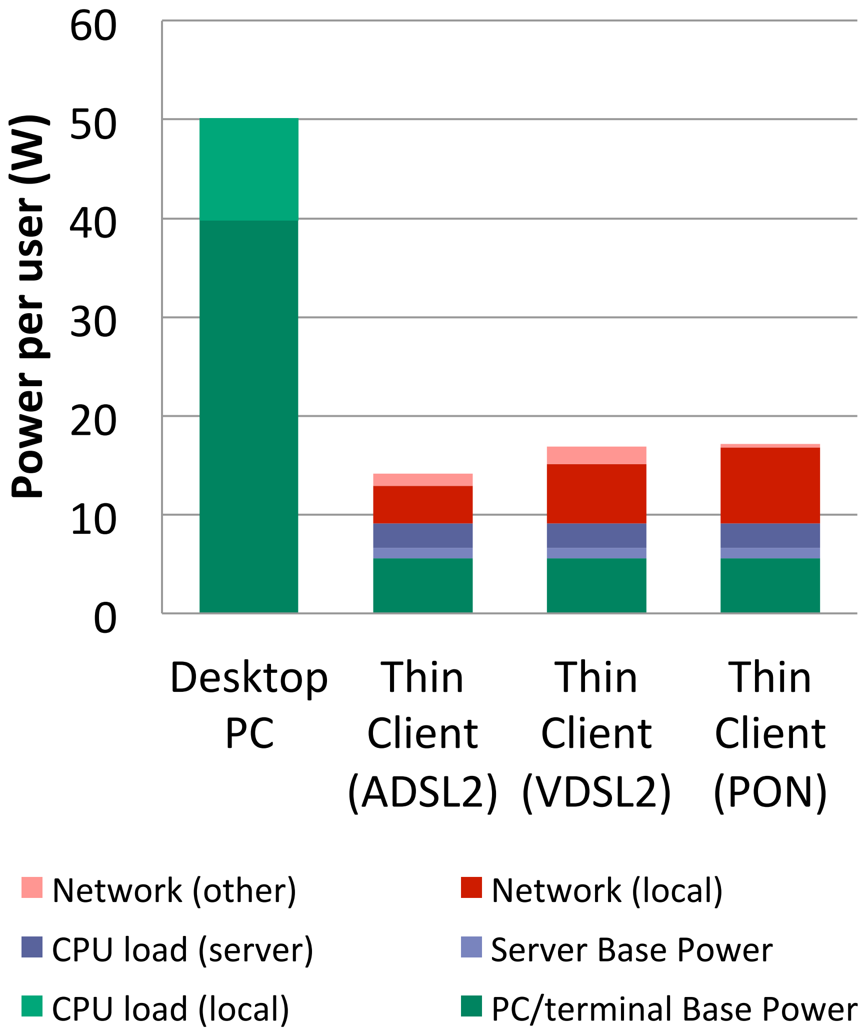
Energy efficient computing? Thin clients + clouds!



Energy efficient computing? Thin clients + clouds!



Energy efficient computing? Thin clients + clouds!



- Clearly lower power consumption for thin client scenario
- Power management of servers is key to handle idle users and variable computation load!

W. Vereecken, et al., *"Power efficiency of thin clients"*, Eur. Trans. Telecomm., Vol. 21, No. 6, Oct. 2010

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   - Energy efficient routing + scheduling
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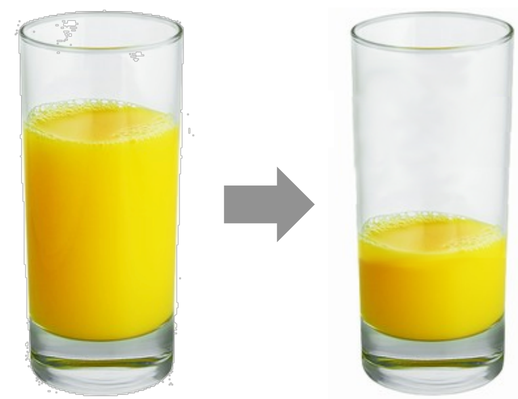
4. Wrap-up

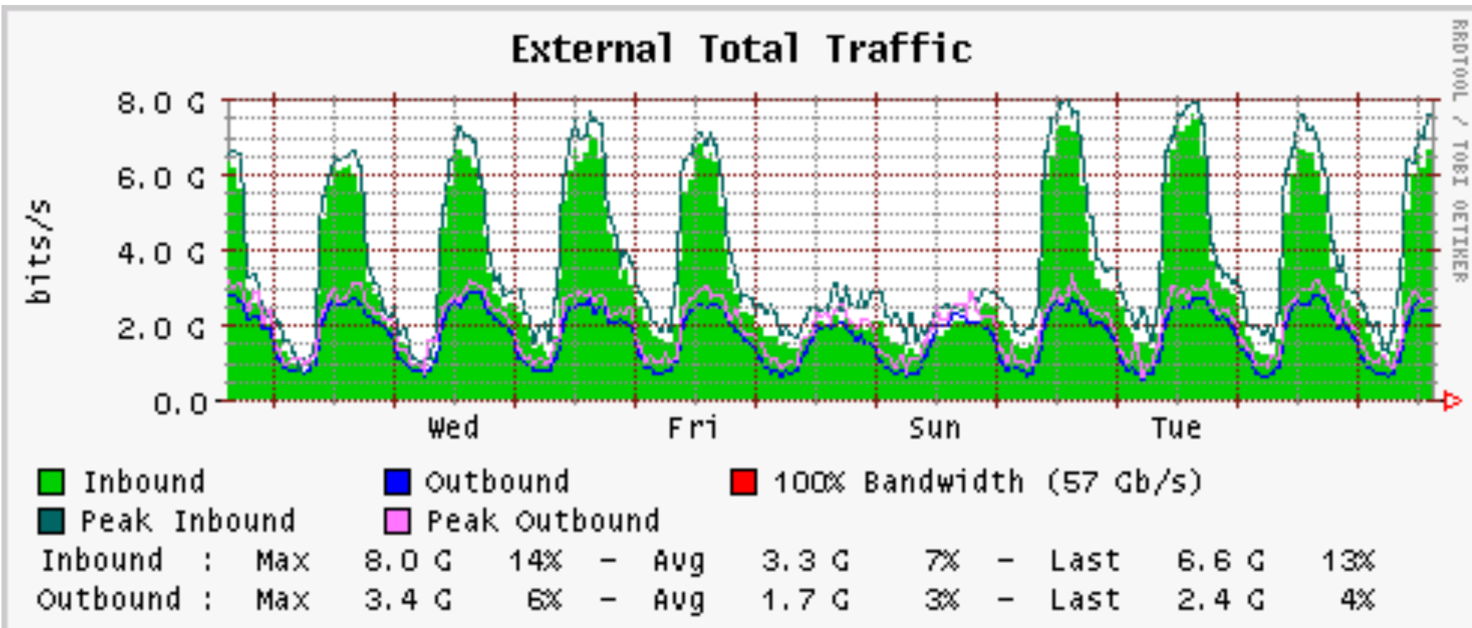


Energy-efficient routing

B. Puype et.al., *"Multilayer traffic engineering for energy efficiency"*, Photonic Netw. Commun., vol. 21, no. 2, Apr. 2011, pp. 127-140

Diurnal traffic variations

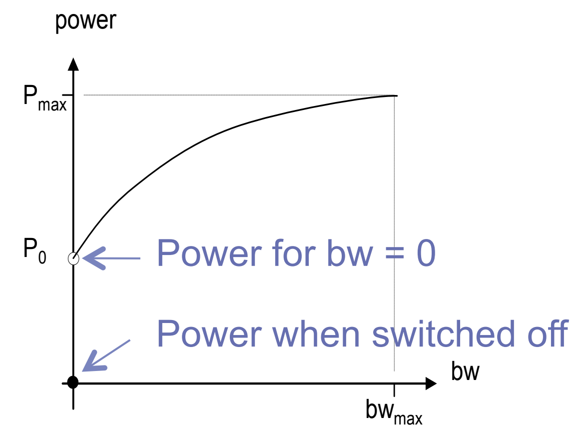
- Night time volume is only a fraction of day time volume
  (20-30% typically; 20% for WiFi hotspot uplinks; 10% for smartphone network)
- Variation amplitude is increasing in recent years



K.Cho et al., Observing Slow Crustal Movement in Residential User Traffic, Proc. ACM CoNext '08
M.Afanasyev et al., Analysis of a Mixed-Use Urban WiFi Network, Proc. IMC '08, 85-98

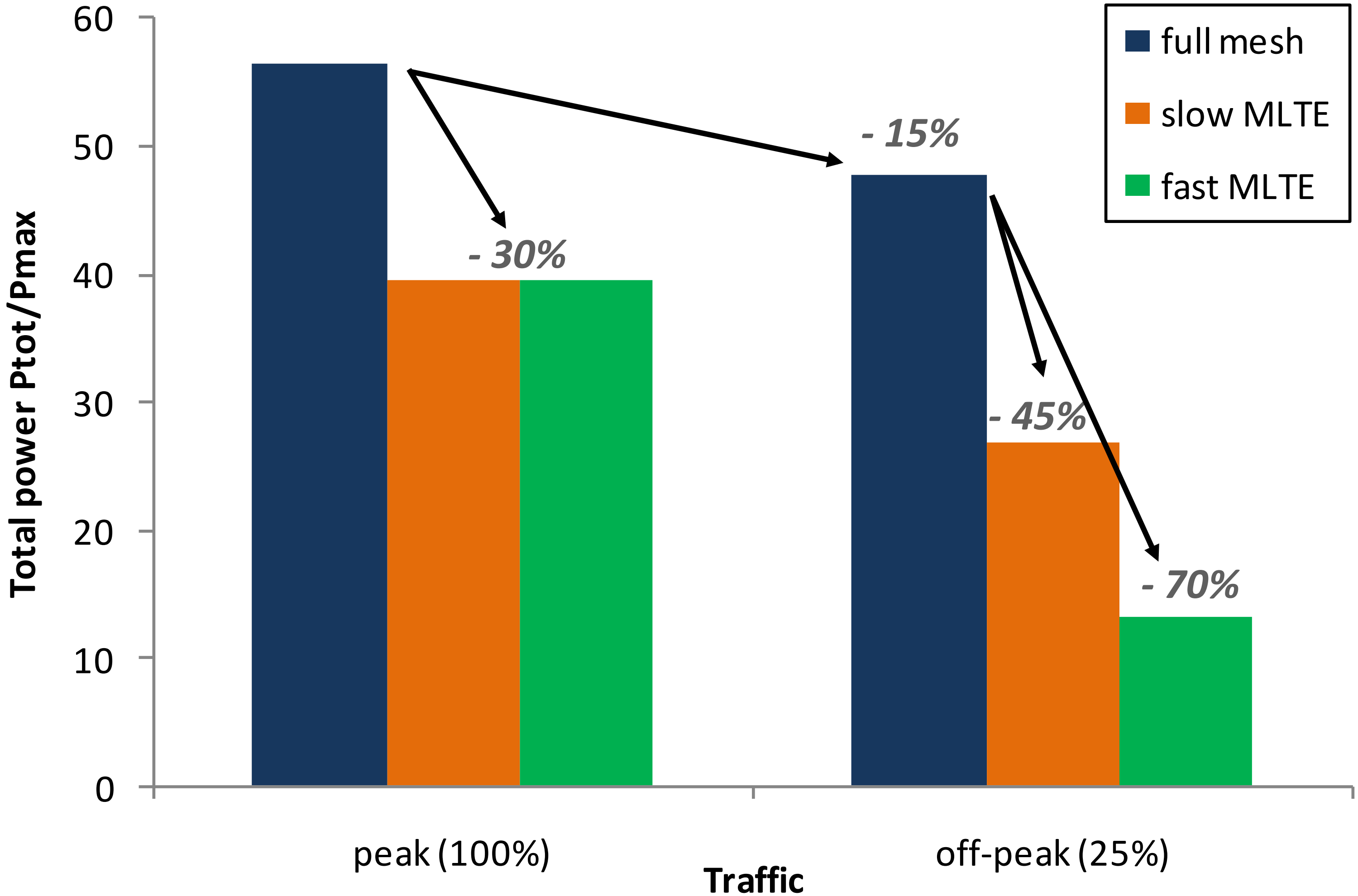
Power optimization techniques

- Energy-efficient multilayer **traffic engineering** (MLTE)
  - Online routing of requests
  - Link metric reflects power characteristic



- Slow MLTE (days) = Logical topology configuration
  - Only set up required IP/MPLS links for traffic of that day
- Fast MLTE (hours) = Reconfiguration & shut-down if off-peak
  - Reroute traffic of shut-down links over remaining links

Effect of MLTE on power



Conclusion for energy-efficient routing

- Opportunities for power savings:
  - Line-card power usage depends on line rate
  - Power scales with bandwidth use
  - Idle power maybe substantial part of max. power

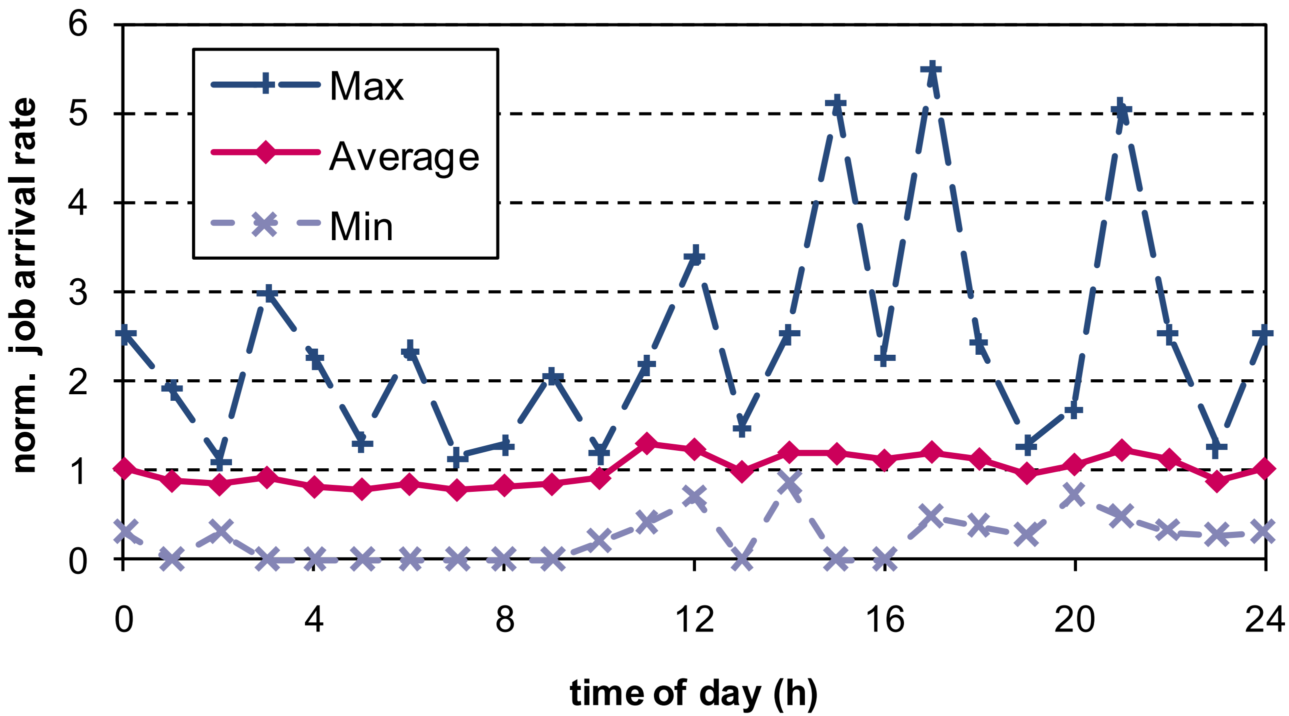
- MLTE = multilayer traffic engineering,
  - Optimizing for link utilization beneficial for power (obviously), but also explicit power optimization is possible *(see paper)*
  - **Even 'slow' MLTE offers substantial savings**
  - **'Fast' MLTE achieves further reduction** (but requires fast control plane)

Energy-efficient scheduling

C. Develder, M. Pickavet, B. Dhoedt and P. Demeester, *"A power-saving strategy for Grids"*, in Proc. 2nd Int. Conf. on Networks for Grid Applications (GridNets 2008), Bejing, China, 8-10 Oct. 2008.

Opportunities for "green grids"

- Fluctuations in server use in LCG Grid



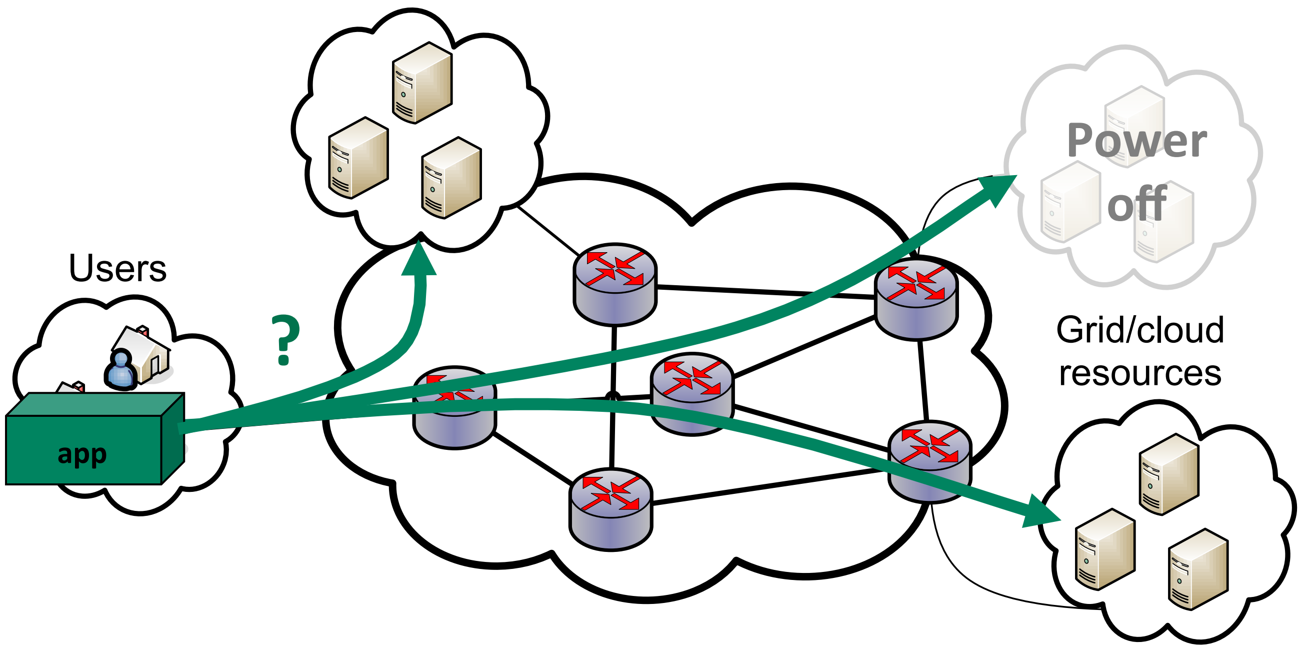
23 LCG Grid sites

$\lambda_{i,norm} = \lambda_i / \lambda_{avg}$
λ_{avg} = avg. over 24h

λ_{max} = max $\lambda_{i,norm}$
λ_{avg} = avg $\lambda_{i,norm}$
λ_{min} = min $\lambda_{i,norm}$

Anycast

- Users do (in general) NOT care where applications are being served
  - E.g., virtual machines in IaaS can be instantiated anywhere
  - E.g., bag-of-tasks grid jobs can be run at any server



C. Develder, J. Buysse, M. De Leenheer, B. Jaumard and B. Dhoedt, *"Resilient network dimensioning for optical grid/clouds using relocation (Invited Paper)"*, in Proc. Workshop on New Trends in Optical Networks Survivability, at IEEE Int. Conf. on Commun. (ICC 2012), Ottawa, Ontario, Canada, 11 Jun. 2012.

When to turn servers off?

Simple power-scheme:

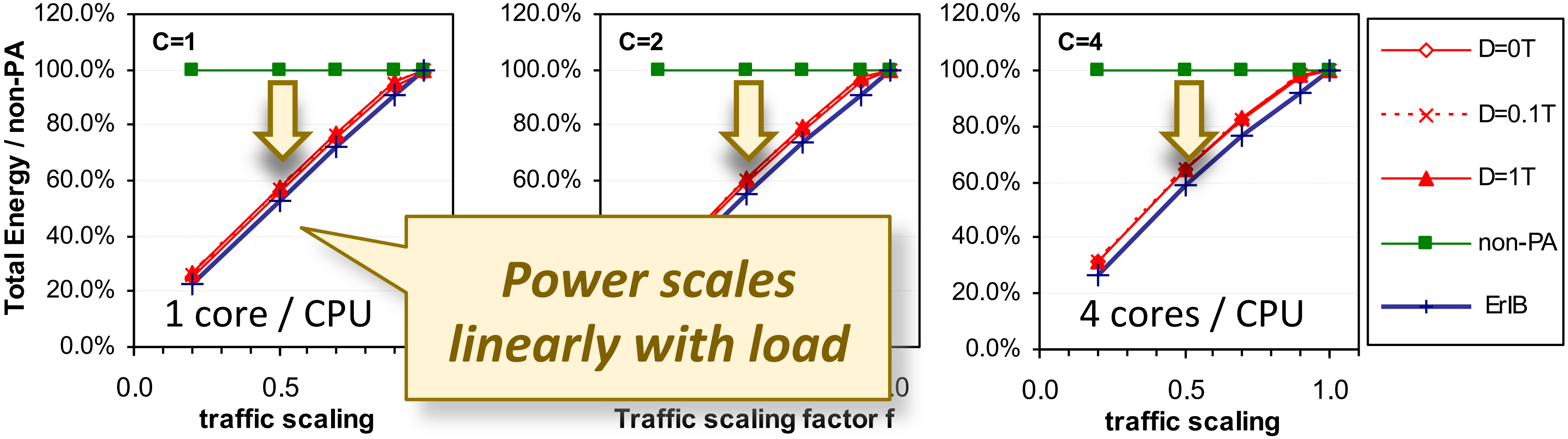
- **Turn off if a time D after a job finishes**, the CPU it was running on is completely idle (i.e., all cores are idle)

Influence of D?

- Poisson process with arrival rate λ:
  P[no arrivals in D] = $e^{-\lambda D}$
- Increasing D: chance we can turn it off will decrease exponentially

Baseline for power-saving strategy will be ErlangB: number of servers from ErlangB formula for max. loss of 5%

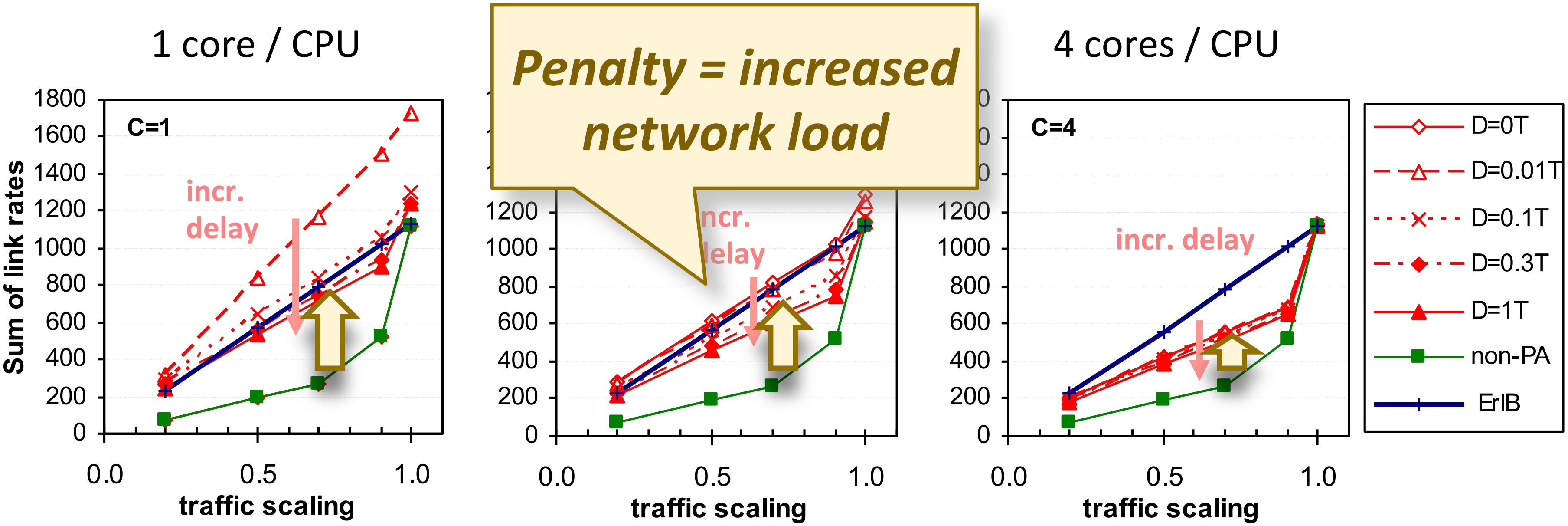
Total server energy



- We achieve power close to theoretical lower bound of ErlangB
- Negligible influence of delay D on *total* power reduction

ErlangB baseline: Power consumption if same fixed number N_s of servers was always on, calculated for traffic s·λ and 5% loss (s = traffic scaling factor)

Link bandwidth use



- Increasing delay = lower excess bandwidth
- Increasing # cores = lower excess bandwidth

Energy-efficient routing + scheduling

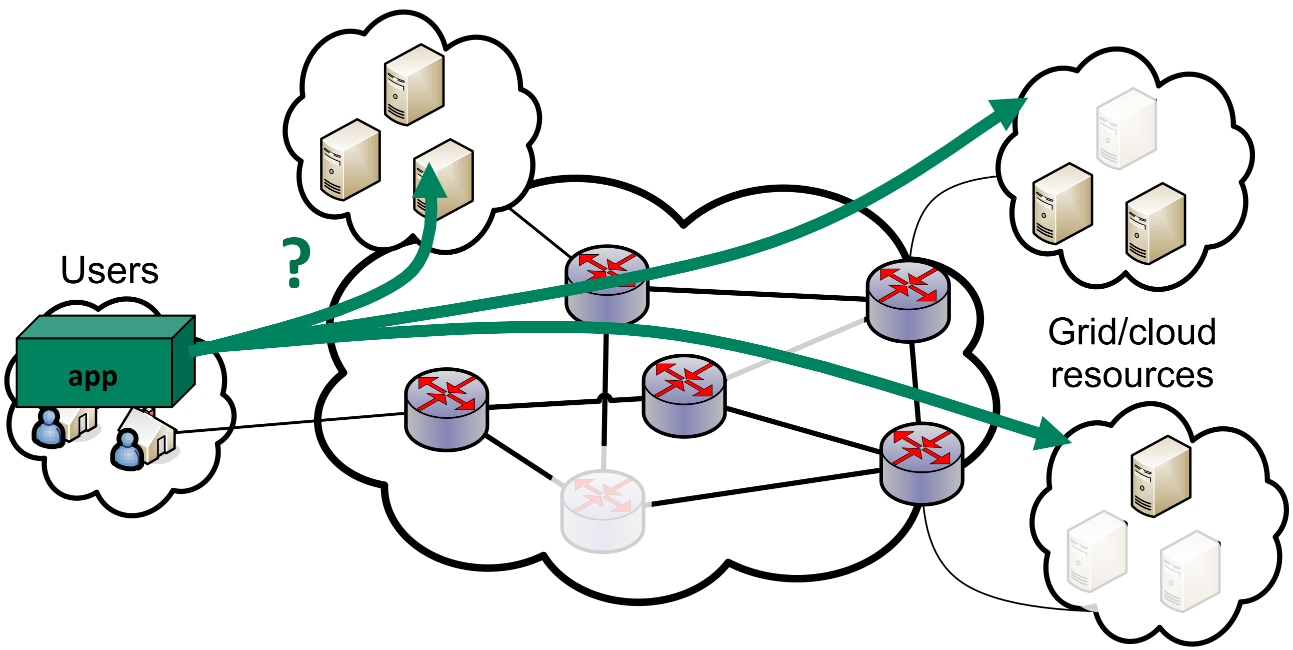
J. Buysse, K. Georgakilas, A. Tzanakaki, M. De Leenheer, B. Dhoedt and C. Develder, *"Energy-Efficient Resource Provisioning Algorithms for Optical Clouds"*, IEEE/OSA J. Opt. Commun. Netw., 2013, to appear.

Exploit anycast to save power:

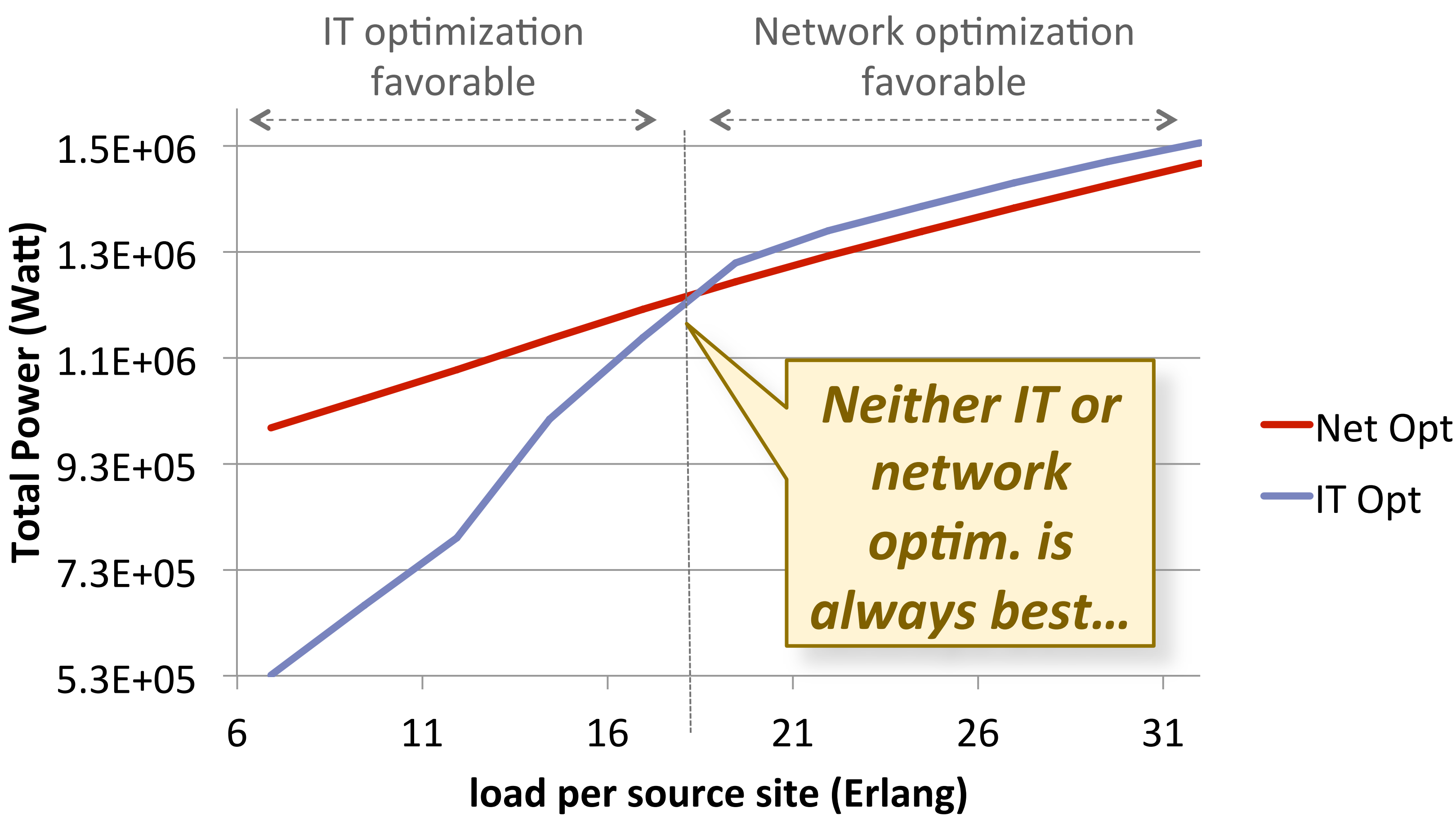
Serve request in optical grid/cloud

- At what data center site?
- Along which route in optical core?

… as to maximize equipment that can be turned off (or to sleep)

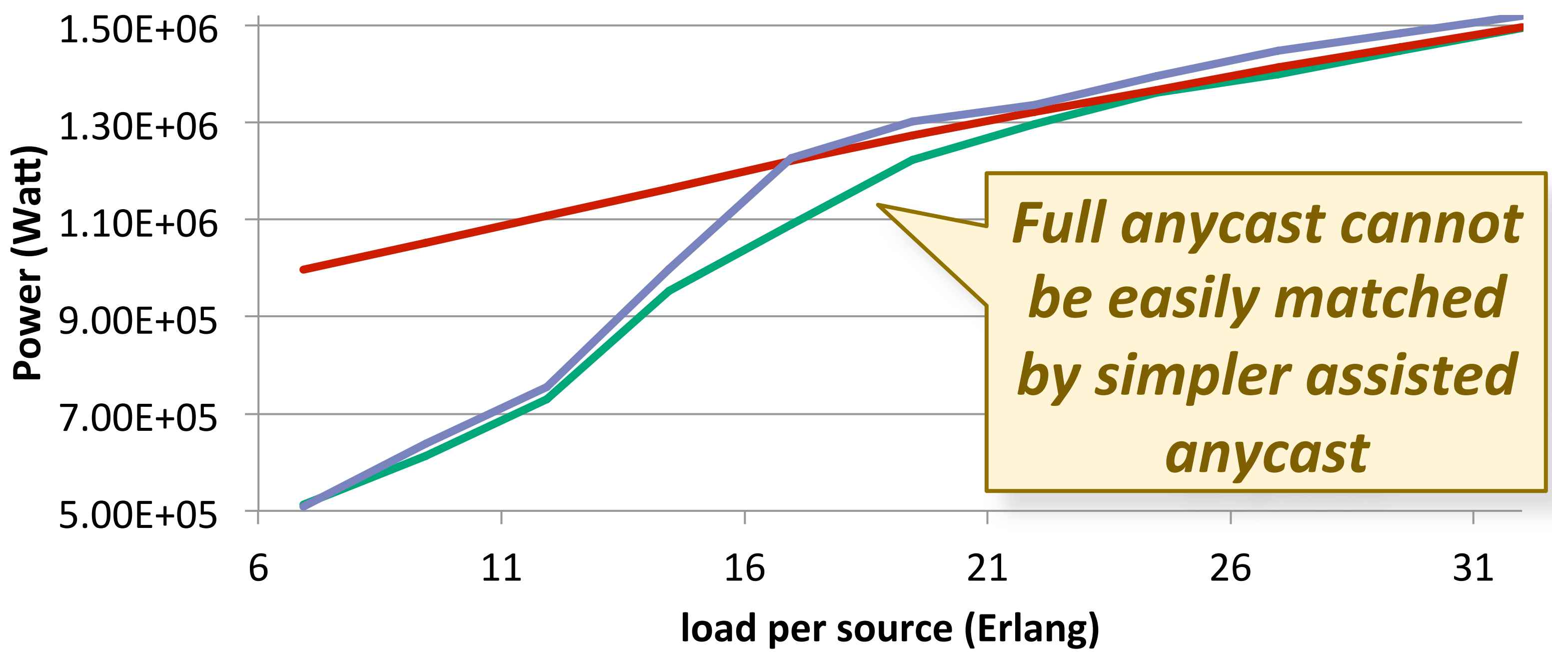


Optimization to network vs data center energy



Assisted anycast vs full anycast?

- Assisted anycast = 1) select data center, 2) find route towards it
  - "**Closest**": choose data center at shortest distance
  - "**Max**": choose data center with maximal load
- **Full anycast** = integrated routing + scheduling



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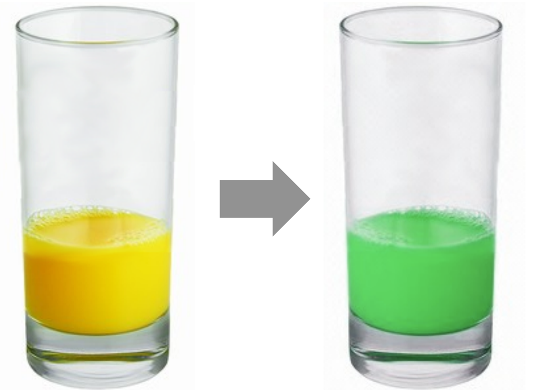
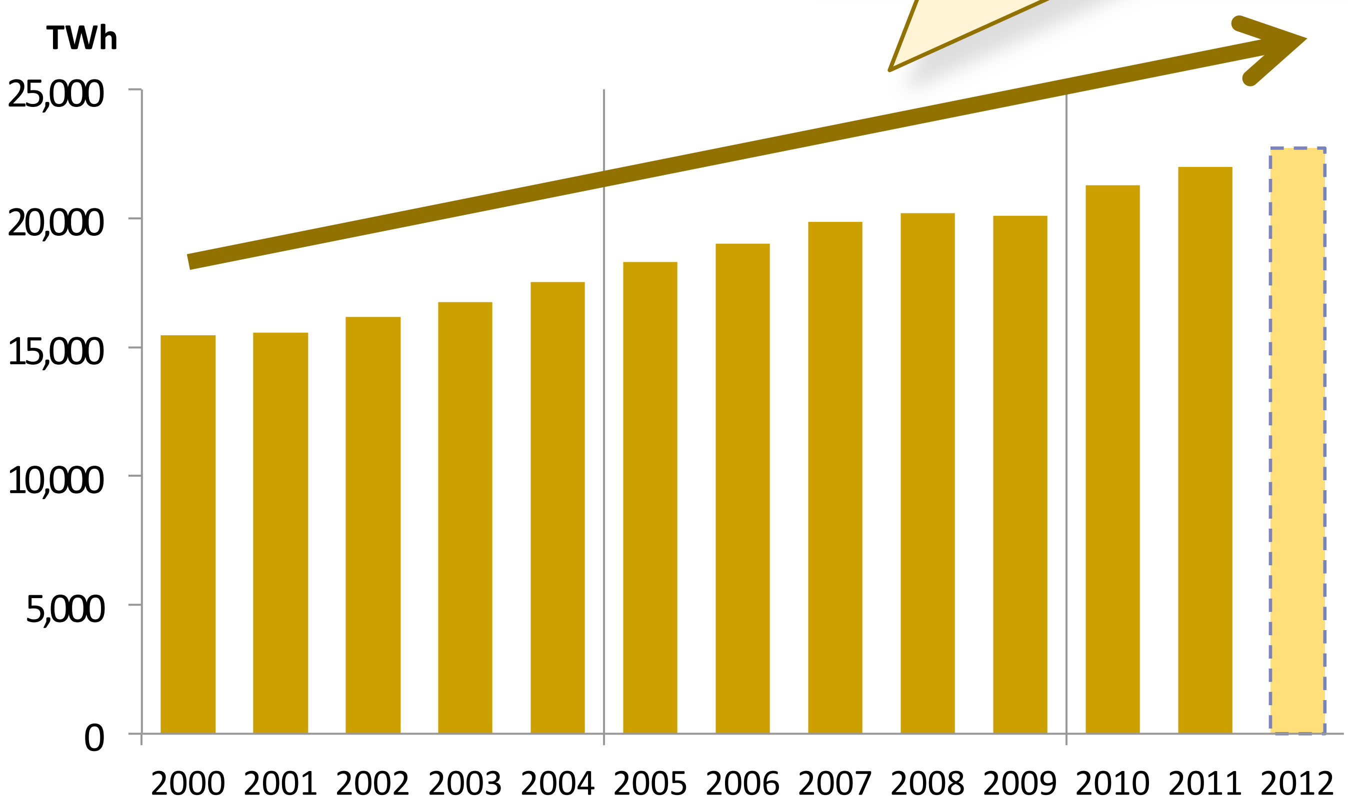


What is the driver for energy efficiency?

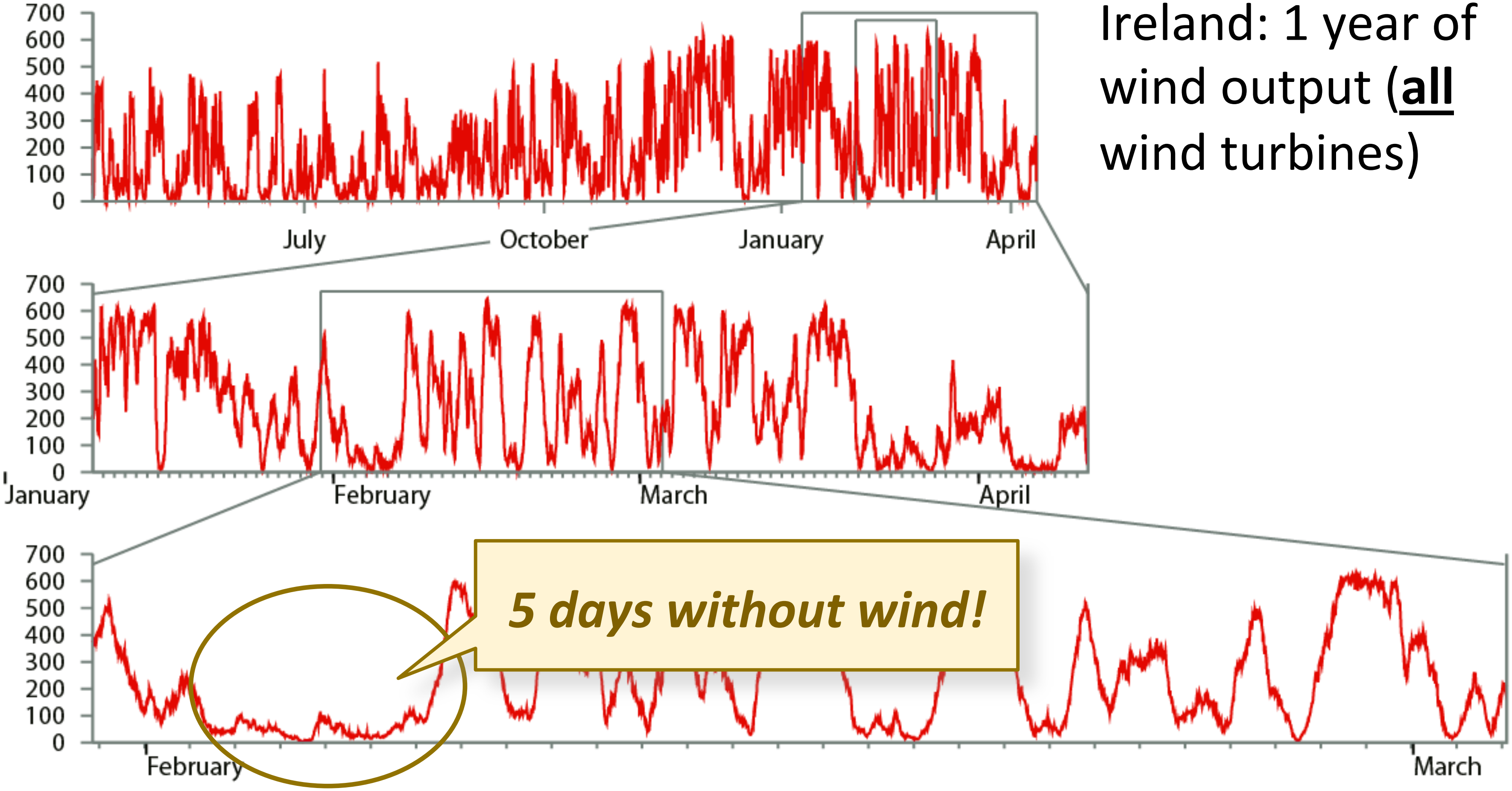
- Cost? √
- Environment (CO2 emission)? ✗

Electricity production rises, despite more energy efficient equipment…



Thus… more renewable energy needed!

Renewable energy: availability?

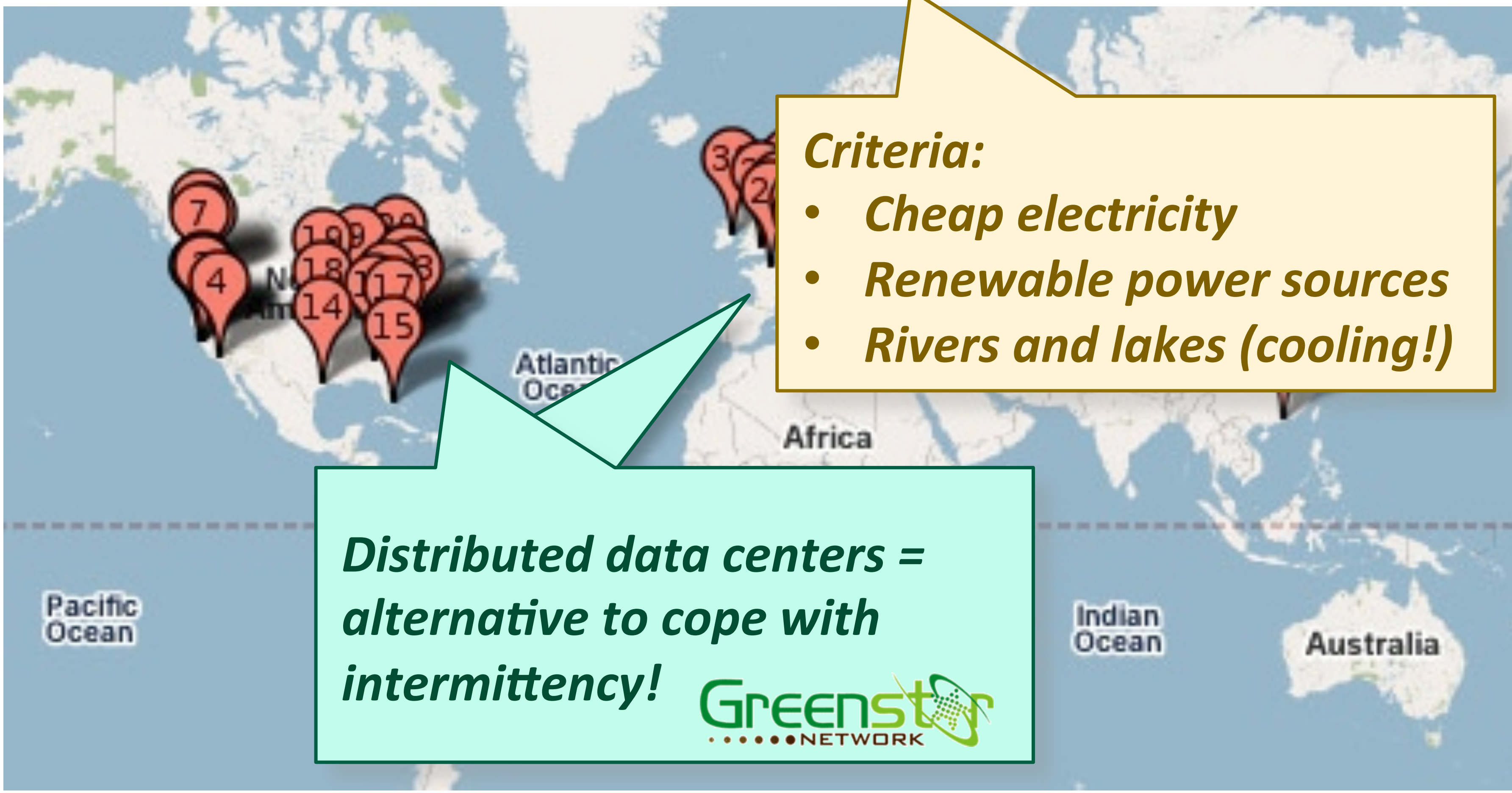


Ireland: 1 year of wind output (**all** wind turbines)

D. McKay, Sustainable Energy — without the hot air, UIT Cambridge, 2008 http://www.withouthotair.com/

Data centers using green energy

Google data center locations (2008)



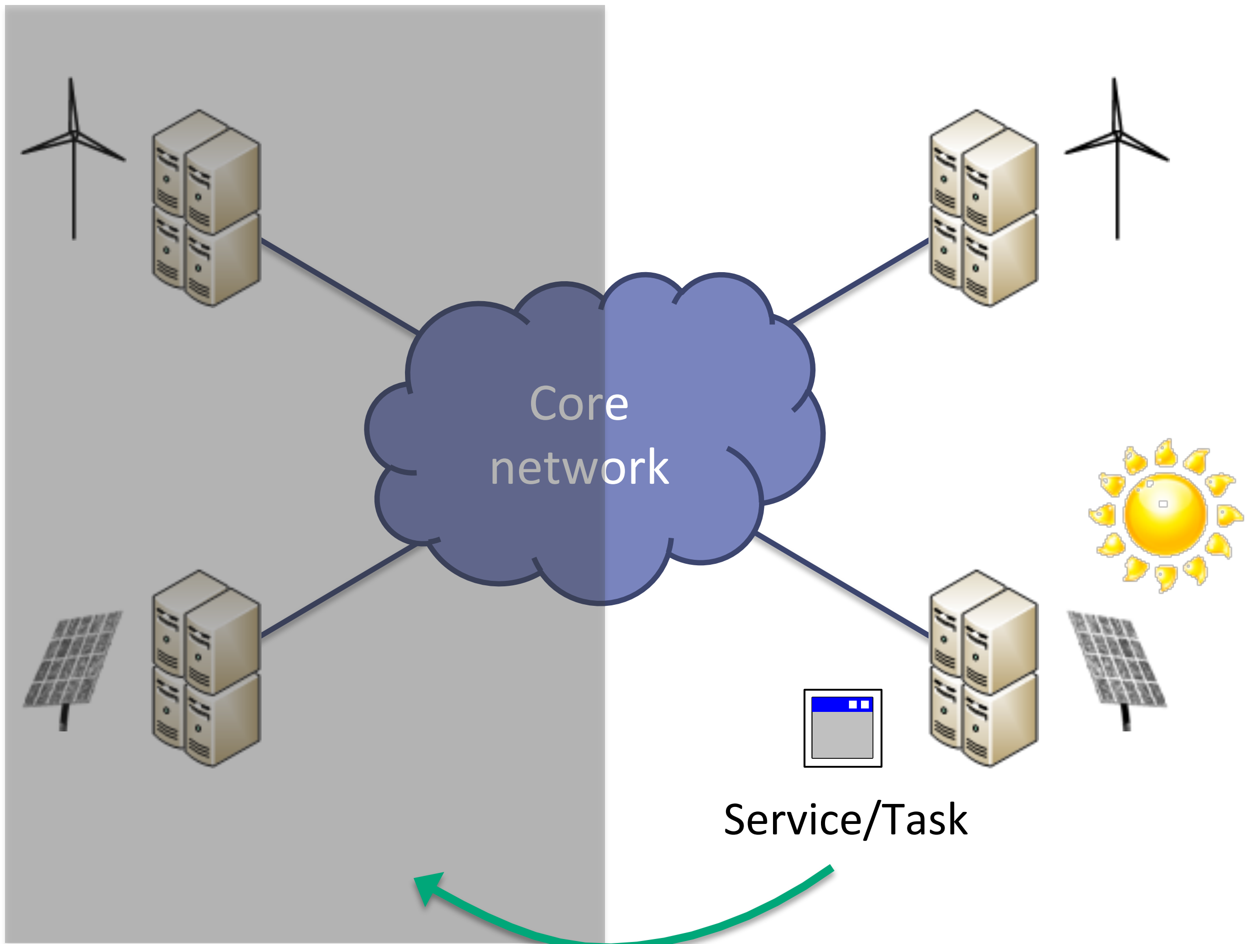
Criteria:

- ***Cheap electricity***
- ***Renewable power sources***
- ***Rivers and lakes (cooling!)***

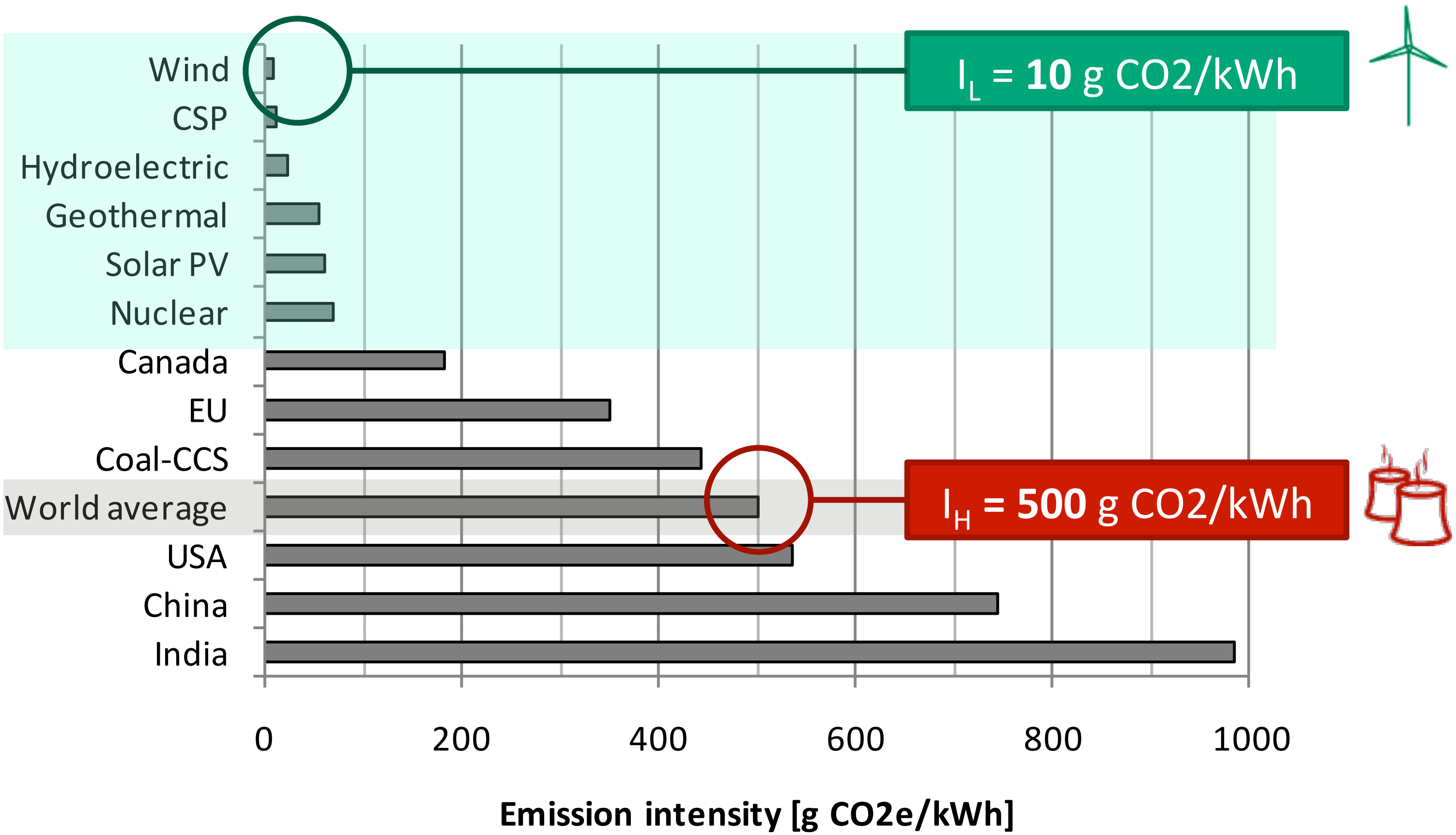
Distributed data centers = alternative to cope with intermittency!

GreenStar NETWORK

"Follow the wind / follow the sun"



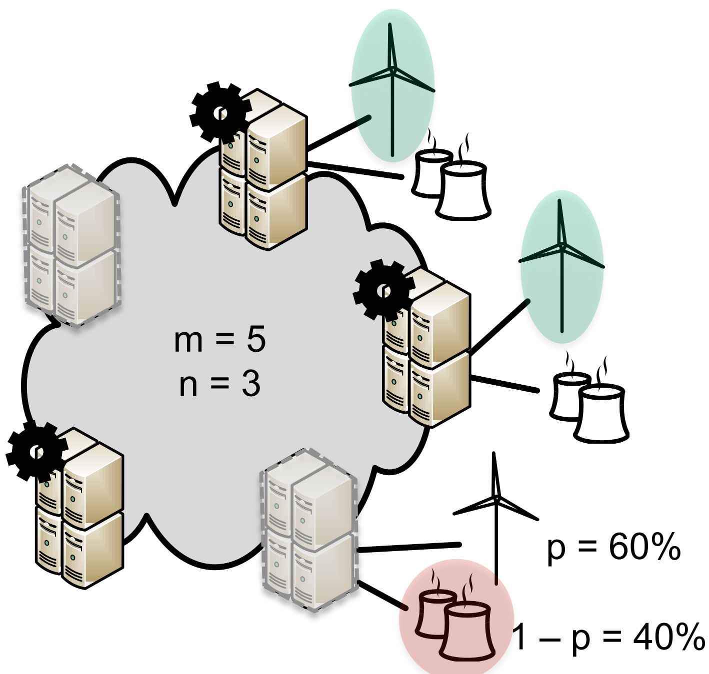
CO2 saving opportunities?



Sources:

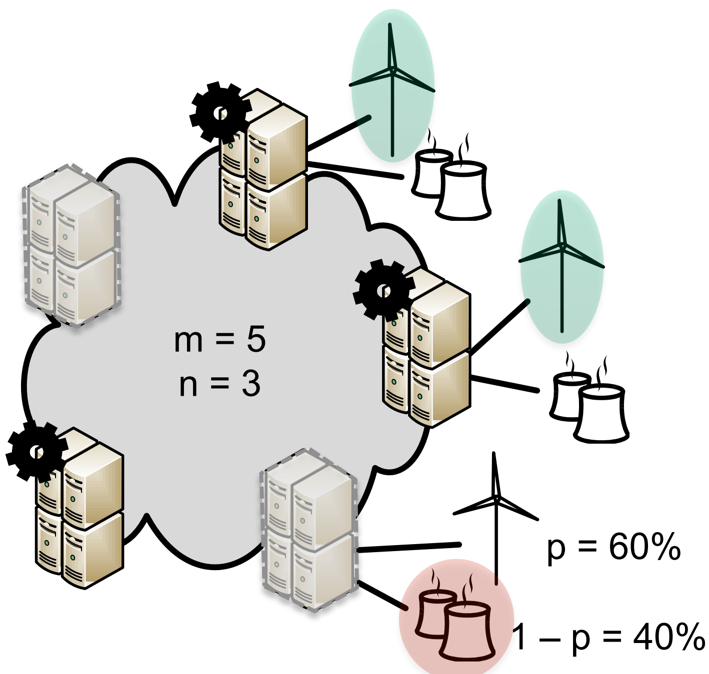
- *M. Jacobson, "Review of solutions to global warming, air pollution, and energy security, Energy & Environmental Science 2", 2009*
- *IEA, "CO2 Emissions from Fuel Combustion – highlights", 2010*

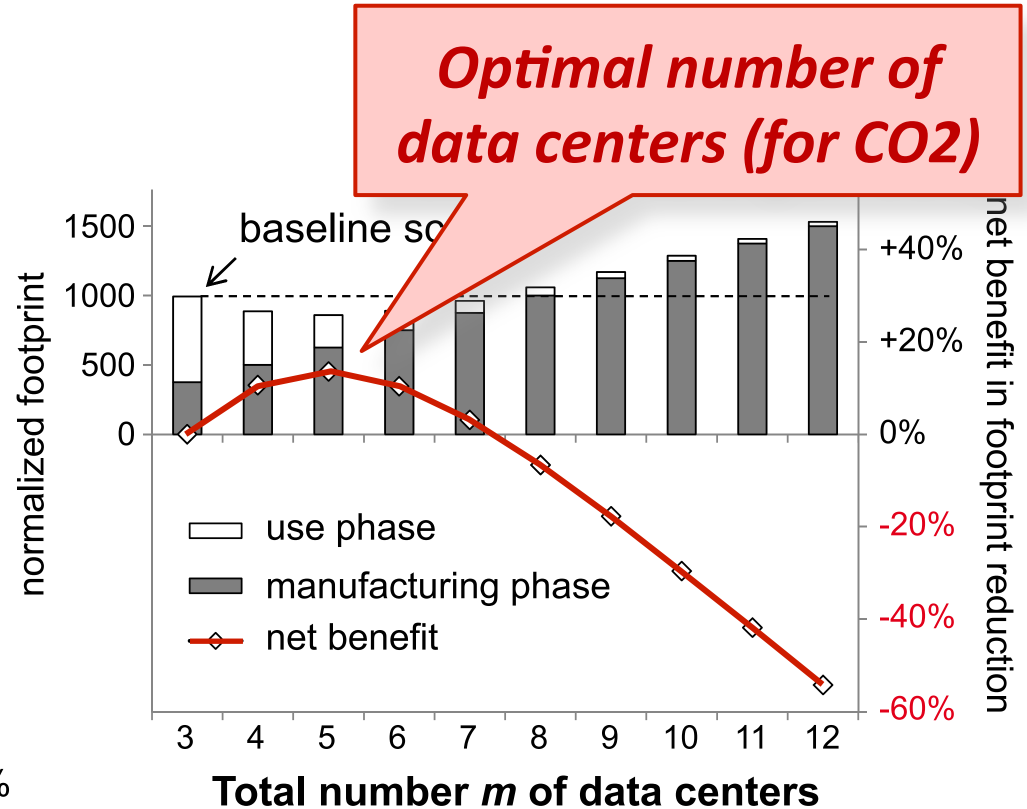
How many data center sites?



W. Van Heddeghem, W. Vereecken, D. Colle, M. Pickavet, and P. Demeester, *“Distributed computing for carbon footprint reduction by exploiting low-footprint energy availability,”* Futur. Gener. Comp. Syst., vol. 28, no. 2, pp. 405–414, Feb. 2012

How many data center sites?





W. Van Heddeghem, W. Vereecken, D. Colle, M. Pickavet, and P. Demeester, *"Distributed computing for carbon footprint reduction by exploiting low-footprint energy availability,"* Futur. Gener. Comp. Syst., vol. 28, no. 2, pp. 405–414, Feb. 2012

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Take-away points

- Energy-efficient computing: **Optical clouds**
  - Exploit anycast!

- Make use of energy efficient technologies
  + Energy-efficient operation
  - Network: Multi-layer traffic engineering
  - Data centers: Eliminate power for unused servers
  - Network + Data centers: Integrated routing & scheduling

- Intermittent sources? – “Follow the wind / the sun”
  - Caveat: carefully dimension your infrastructure

Thank you … any questions?

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