Leveraging Renewable Energy in Data Centers: Present and Future

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Motivation

- Data centers = machine rooms to giant warehouses
- Consume massive amounts of energy (electricity)

Electricity consumption of US DCs [JK’11]

Electricity consumption of WW DCs [JK’11]
Motivation

- Electricity comes mostly from burning fossil fuels

Electricity sources in US & WW [DOE’10]

Can we use renewables to reduce this footprint?
Outline

• DC energy usage and carbon footprint
• Reducing footprint with renewables: 2 approaches
• Our target and research challenges
• Software for leveraging solar energy
• Parasol: our solar micro-data center
• Current and future works
• Conclusions
Greening DCs

1. Power purchase agreement, off-site generation
   - Renewable energy produced at the best location
   - Energy losses: ~15% [IEC’07]
   - Example: Google buys wind power from NextEra
Greening DCs

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2. Co-location, self-generation
   - Lower peak power, energy costs with self-generation
   - Location may not be ideal for DC or renewable plant
   - Examples: MSFT placed DC near a hydro plant in OR
     Apple built a 40MW solar array in NC

• No approach is perfect
Outline

• DC energy usage and carbon footprint
• Reducing footprint with renewables
• Our target and research challenge
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Our research target

• Co-location or self-generation with solar and/or wind
  – Pros: Clean and available
  – Cons: Space and cost
Solar and wind are clean
Solar and wind are clean

[Sovacool’08]
Solar is more available in the US
Space: Solar PV efficiencies are increasing

[IEA’10]

[chart showing the increase in efficiency rates of PV modules from 2008 to 2030, categorized into different technologies:
- I – Crystalline silicon technologies: single crystalline, multi-crystalline, ribbon
- II – Thin-film technologies: cadmium-telluride, copper-indium/gallium-diselenide/disulphide and related II-VI compounds, thin-film silicon
- III – Emerging technologies and novel concepts
- IV – Concentrating photovoltaics
  - Quantum wells, up-down converters, intermediate band gaps, plasmonics, thermo-photovoltaics, etc]

RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY
Space: Solar PV capacity factors today

[Chart showing solar PV capacity factors for Erfurt, Rutgers, Canberra, and Phoenix.]

[PVOutput’12]
Cost of solar PV energy is decreasing

Grid electricity prices have been increasing: 30%+ since 1998 [EIA’12]
Cost of solar PV energy is decreasing

The graph shows the decrease in the cost of solar PV energy over time from 1985 to 2029. The cost is measured in 2011 Dollars per Watt. The graph includes data for installed panels and inverters, with specific annotations for spikes in demand and world-wide recession, indicating that the cost has decreased back to historical levels after these events.

[DOE’11, Solarbuzz’12]
Cost of solar PV energy is decreasing

With incentives, the installed price can go down by another 40-60%
### Solar space and cost: Present and future

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Assuming 30% server utilization, 50% solar energy, NJ capacity factor, and 1 row of panels
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Assuming self-generation and federal + state incentives

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Assuming above costs, NJ capacity factor, and NJ grid energy prices
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Assuming above costs, NJ capacity factor, and NJ grid energy prices

Wind takes ~12x less space and is ~3x cheaper
Main challenge: Supply of power is variable!

- Batteries and net metering are not ideal
- We need to match the energy demand to the supply
Main challenge: Supply of power is variable!

• Many research questions:
  – What kinds of DC workloads are amenable?
  – What kinds of techniques can we apply?
  – How well can we predict solar energy availability?
  – If batteries are available, how should we manage them?
  – Can we leverage geographical distribution?

• Building hardware & software to answer questions
Outline

• DC energy usage and carbon footprint
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• Hardware and software for leveraging solar energy
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Green DC software

- Follow the renewables [HotPower’09, SIGMETRICS’11]
- Duty cycle modulation with sleep states [ASPLOS’11]
- Quality degradation for interactive loads [UCB-TR’12]
- Adapt the amount of batch processing [HotPower’11]
- Delay batch jobs while respecting deadlines
  - GreenSlot [SC’11], GreenHadoop [Eurosys’12]
Overall “delay-until-green” approach

• Predict green energy availability
  – Weather forecasts

• Schedule jobs
  – Maximize green energy use
  – If green not available, consume cheap brown electricity

• May delay jobs but must meet deadlines

• Send idle servers to sleep to save energy

• Manage data availability if necessary
GreenHadoop scheduling

Estimate the energy required by jobs

Job5
Job1
Job3
Job4
Job2
Job6
GreenHadoop scheduling

Assign green energy first

Job5
Job3
Job2
Job6

Predict energy availability
(weather forecast)

Off-peak
On-peak
Off-peak

Time
Power

Now
GreenHadoop scheduling

Assign cheap brown energy

Off-peak
On-peak
Off-peak

Previous peak
Now

Time

Power
GreenHadoop scheduling

Assign expensive energy

Current power → Active servers

Active servers

Off-peak On-peak Off-peak

Power

Time

Now
GreenHadoop scheduling

As time goes by...

the number of active servers changes
GreenHadoop for Facebook workload

Hadoop

31% more green
39% cost savings

GHadoop
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The Rutgers Parasol Project
Parasol: Our hardware prototype

- Unique research platform
  - Solar-powered computing
  - Remote DC deployments
  - Software to exploit renewables within and across DCs
  - Tradeoff between renewables, batteries, and grid energy
  - Free cooling, wimpy servers, solid-state drives
Parasol details

• Steel structure on the roof
  – Container hosts 2 racks of IT
  – 16 solar panels: 3.2 kW peak

• Backup power
  – Batteries and power grid

• IT equipment
  – 64 Atom servers (so far): 1.7 kW

• Cooling
  – Free cooling: 10 -- 400 W
  – Air conditioning: 2 kW
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Current and future works

• Provisioning the solar array and batteries
• Free cooling and its costs/benefits, world-wide
• DC placement with probabilistic green energy guarantees
• GreenNebula: follow the renewables

• HotPower’09, IGCC’10, SC’11, EuroSys’12, IGCC’13, ASPLOS’13
Conclusions

• Reduce the carbon footprint of ICT, data centers
• Topic is interesting and has societal impact
• Prior work on software and hardware
• Lots left to do...

http://parasol.cs.rutgers.edu