Leveraging Renewable Energy in Data Centers: Present and Future

Ricardo Bianchini
Department of Computer Science

Collaborators: Josep L. Berral, Inigo Goiri, Jordi Guitart, Md. Haque, William Katsak, Kien Le, Thu D. Nguyen, Jordi Torres
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 carbon 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: Grid-centric approach

• Pump renewables into the grid

• Pros:
  – If the grid is available, power is available
  – DC operator need not worry about renewable plants
  – Plants can be placed at the best possible locations

• Cons:
  – Energy losses of ~15% [IEC’07]
  – Dependence on the power grid or diesel generators

• Example: Google buys wind power from NextEra
Greening DCs: Co-location approaches

• (1) Build DC near a renewable plant or (2) self-generate
• Pros:
  – Reduced energy losses: ~5%
  – No dependence on the grid
  – Lower peak-power/energy costs, after amortization period (2)
• Cons:
  – Location may not be good for DC (1) or renewable plant (2)
  – Energy may have already been committed (1)
  – Need to install and maintain renewable plant (2)
• Examples: Microsoft built DC near hydro plant in OR (1)
  Apple is building 20MW solar array in NC (2)
Outline

• DC energy usage and carbon footprint
• Reducing carbon with renewables
• **Our target and research challenge**
• Software and hardware for leveraging solar energy
• Current and future works
• Conclusions
Our target

• No approach is perfect
  – Different DC operators may take different approaches

• 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 CO2e per KWh over lifetime

[Sovacool’08]
Solar is more available in the US

Wind

Solar

[NREL’12]
Space: Solar PV efficiencies are increasing

[IEA’10]
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

- Installed
- Panels
- Inverters

2011 Dollars per Watt


[DOE’11,Solarbuzz’12]

- spike in demand
- world-wide recession
- back to historical levels
Cost of solar PV energy is decreasing

With incentives, the installed price can go down by another 50-60%
### Solar space and cost: Present and future

#### Space as a factor of rack area

<table>
<thead>
<tr>
<th>Density per rack</th>
<th>Present</th>
<th>Future (2020-2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8kW (200W 1U servers)</td>
<td>~47x</td>
<td>~24x</td>
</tr>
<tr>
<td>2kW (25W 0.5U servers)</td>
<td>~12x</td>
<td>~6x</td>
</tr>
</tbody>
</table>

Assuming 30% server utilization, 50% solar energy, NJ capacity factor, and 1 row of panels.

#### Cost per Watt

<table>
<thead>
<tr>
<th>Cost per Watt</th>
<th>Present</th>
<th>Future (2020-2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>~$2.30</td>
<td>&lt; $1.20</td>
<td></td>
</tr>
</tbody>
</table>

Assuming self-generation and federal + NJ incentives.

#### Time to amortize cost

<table>
<thead>
<tr>
<th>Time to amortize cost</th>
<th>Present</th>
<th>Future (2020-2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>~12 years</td>
<td>&lt; 6 years</td>
<td></td>
</tr>
</tbody>
</table>

Assuming above costs, NJ capacity factor, and NJ grid energy prices.
## Solar space and cost: Present and future

<table>
<thead>
<tr>
<th>Space as a factor of rack area</th>
<th>Present</th>
<th>Future (2020-2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density per rack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8kW (200W 1U servers)</td>
<td>~47x</td>
<td>~24x</td>
</tr>
<tr>
<td>2kW (25W 0.5U servers)</td>
<td>~12x</td>
<td>~6x</td>
</tr>
</tbody>
</table>

Assuming 30% server utilization, 50% solar energy, NJ capacity factor, and 1 row of panels

<table>
<thead>
<tr>
<th>Cost per Watt</th>
<th>Present</th>
<th>Future (2020-2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~$2.30</td>
<td>&lt; $1.20</td>
</tr>
</tbody>
</table>

Assuming self-generation and federal + NJ incentives

<table>
<thead>
<tr>
<th>Time to amortize cost</th>
<th>Present</th>
<th>Future (2020-2030)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~12 years</td>
<td>&lt; 6 years</td>
</tr>
</tbody>
</table>

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?
  – Should we allow programmers to specify what can be done?
  – How well can we predict solar 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
• Reducing carbon with renewables
• Our target and research challenges
• Hardware and software for leveraging solar energy
• Current and future works
• Conclusions
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 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 (EWMA)

Job1

Job3

Job4

Job5

Job2

Job6
GreenHadoop scheduling

Assign green energy first

Job5
Job3
Job2
Job6

Predict energy availability
(weather forecast)

Off-peak
On-peak
Off-peak

Power

Now
Time
GreenHadoop scheduling

Assign cheap brown energy

Previous peak

On-peak

Off-peak

Time

Power

Off-peak

On-peak

Off-peak

Now

Now
GreenHadoop scheduling

Assign expensive energy

Current power → Active servers

Active servers

Off-peak  On-peak  Off-peak

Power

Now  Time
GreenHadoop scheduling

As time goes by...

the number of active servers changes
Energy prediction vs actual

Actual data from the Rutgers solar farm (scaled down to our 16-node cluster)
Energy prediction vs actual

Actual data from the Rutgers solar farm (scaled down to our 16-node cluster)
GreenHadoop for Facebook workload

31% more green
39% cost savings
Outline

• DC energy usage and carbon footprint
• Reducing carbon with renewables
• Our target and research challenges
• Software and hardware for leveraging solar energy
• Current and future works
• Conclusions
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
  – Full monitoring: resources, power, temperature, air
Parasol details

• Installed on the roof
• Steel structure
  – Container to host the IT
  – 16 solar panels: 3.2 kW peak
• Backup power
  – Batteries: 32 kWh
  – Power grid
• IT equipment
  – 2 racks
  – 64 Atom servers (so far): 1.7 kW
  – 2 switches and 3 PDUs
• Cooling
  – Free cooling: 110 W or 400 W
  – Air conditioning: 2 kW
  – Heating: 3 kW
Outside and inside Parasol
Outline

• DC energy usage and carbon footprint
• Reducing carbon with renewables
• Our target and research challenges
• Software and hardware for leveraging solar energy
• Current and future works
• Conclusions
Current and future works

• DC placement with probabilistic guarantees
• GreenNebula
• Smart management of energy sources
• Green SLAs
• Tradeoff between performance and green energy use
• Collect and make sense of the monitoring data
Conclusions

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

More info -- http://parasol.cs.rutgers.edu