Building Green Cloud Services at Low Cost

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Motivation

• Cloud services require thousands of servers
• Use multiple "mirror" datacenters
• Billions of dollars building and operating datacenters
• Datacenter costs depend on location
Green datacenters

• Datacenters consume large amounts of energy
• High energy cost and carbon footprint
  • Brown electricity: coal and natural gas
• Connect datacenters to green sources: solar, wind
• Some operators require green energy
  • For example, 50% of datacenter energy to be "green"

Apple DC in Maiden, NC

40MW solar farm
Challenges in green datacenters

- Solar and wind energy availability is variable
  - Use grid brown electricity
  - Use stored energy
- Use green energy
  - Energy storage: net metering and batteries
  - Multiple green datacenters
Placing green datacenters

- Datacenter with onsite renewable plant(s)
- Renewable costs depend on location
  - Land costs
  - Renewable energy availability

Wind availability

Solar availability
Workloads in green datacenters

- Multiple locations
  - Changing green energy availability over time
  - Use available green energy

- Workload follows the renewables
  - Consider migration overheads
  - Manage data in multiple locations
Goals

• **Siting and provisioning**
  • Pick locations
  • Datacenter sizes
  • Co-located solar/wind farm sizes
  • Green energy requirement (e.g., 50% green energy)

• **Managing workloads in green datacenter networks**
  • Follow-the-renewables policy
  • HPC jobs in virtual machines (VMs)
  • Network latency not an issue and "easy" to migrate load
Placement framework

- Datacenter costs
  - Depend on location and size

- Capital expenses (CAPEX)
  - Datacenter building
  - Cooling infrastructure
  - Servers and network
  - Connection to network and electrical grid
  - Renewable equipment and batteries
  - Ammortization and financing

- Operational expenses (OPEX)
  - IT and cooling operation
Formulating the problem

• Optimization goal
  • Minimize total cost (CAPEX and OPEX)

• Constraints
  • Green energy requirement (e.g., 50% green)
  • Datacenter availability constraint

• Output
  • Location and datacenter size
  • Renewable plant type and size
  • Battery size (if used)
Solving the problem

• Problem not linear: new solution approach
  • Initial location filtering
  • Simplified problem (MILP)
  • Simulated annealing enhanced with heuristics
Input data: location-related

- 1373 locations around the world
- Meteorological data
  - Typical meteorological year (TMY)
  - Solar irradiation
  - Wind speed
  - Temperature
- Grid electricity costs
  - Power plants
  - Transmission lines
  - Energy cost
- Other datacenter costs
  - Major network backbones
  - Land costs
Input data: capacity factors

- Solar/wind energy generation
  - Solar panel model (W/m\(^2\)→W)
  - Wind turbine model (m/s→W)
  - Renewable plant size (W)
  - Location weather data
- Capacity factor
  - Actual power ratio over capacity
  - Over a full year
- Solar is more available
  - Wind is higher in few locations
- Location correlation
  - Solar/wind availability
  - Temperature (→PUE)
Green datacenter placement

- 50MW computation capacity
- 50% renewable energy requirement
- Net metering to handle variability

![Chart showing costs and resources](chart.png)

**Right amount of capacity, no resources idle**

- Mount Washington (New Hampshire)
  - Land wind
  - Building wind farm
  - Network bandwidth
  - Brown energy
  - Connection grid/net
  - IT equipment
  - Land DC
  - Building DC

- Grissom (Indiana)
  - Land wind
  - Building wind farm
  - Network bandwidth
  - Brown energy
  - Connection grid/net
  - IT equipment
  - Land DC
  - Building DC
Green energy requirement

- Build a 50MW network using net metering

Wind more cost-effective than solar (3x cheaper)
Green cost overhead 13% for 50% green always <20%
Placement with no green energy storage

Massive renewable plants

Everything replicated

Mexico

Guam

Zimbabwe

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<th>Location</th>
<th>Land wind</th>
<th>Building wind farm</th>
<th>Land solar</th>
<th>Building solar</th>
<th>Network bandwidth</th>
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Impact of green energy storage

- Green energy storage mitigates variability
  - Batteries ~2x more expensive than net metering
  - No storage ~5x more expensive

- One case where solar more cost-effective than wind
  - No storage and high green energy requirement
  - More predictable
How to operate a green datacenter network?

• Feasibility of "follow the renewables“
• Run HPC jobs
  • No latency requirements
• Need to move load between locations
  • VMs for live migration
  • Distributed file system
• Policy to follow the renewables
  • Predict green energy availability per site
  • Consider migration overheads
  • Version of the original placement MILP
GreenNebula

- Based on OpenNebula
  - Scheduling policy to place and migrate VMs across datacenters
  - Distributed file system: append only, diff...
GreenNebula results

- Validated in prototype system
  - Migration between Barcelona and New Jersey
- Placement with 3 locations (previous example)
  - 100% green energy with no energy storage
Conclusions

• Building a green network of datacenters
  • Partially powered by on-site renewables

• Siting and provisioning
  • Quantify cost of being green
  • Energy storage costs
  • Usually wind is cheaper
  • Solar more reliable for high green energy requirements
  • Net metering most “cost-effective” storage medium
  • Batteries only slightly more expensive up to 75% green

• GreenNebula
  • Follow-the-renewables VM scheduler
  • Extend siting optimization problem
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