EmPowering the Power Grid through ICT

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University of Groningen (NL)
Electricity is a utility...
Top 10 countries by market share of new car sales in 2013 by electric-drive segment (1)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Country</th>
<th>PEV market share(%)</th>
<th>BEV market share(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Norway</td>
<td>6.10%</td>
<td>5.75%</td>
</tr>
<tr>
<td>2</td>
<td>Netherlands</td>
<td>5.55%</td>
<td>0.83%</td>
</tr>
<tr>
<td>3</td>
<td>Iceland</td>
<td>0.94%</td>
<td>0.79%</td>
</tr>
<tr>
<td>4</td>
<td>Japan</td>
<td>0.91%</td>
<td>0.73%</td>
</tr>
<tr>
<td>5</td>
<td>France</td>
<td>0.83%</td>
<td>0.69%</td>
</tr>
<tr>
<td>6</td>
<td>Estonia</td>
<td>0.73%</td>
<td>0.51%</td>
</tr>
<tr>
<td>7</td>
<td>Sweden</td>
<td>0.71%</td>
<td>0.39%</td>
</tr>
<tr>
<td>8</td>
<td>United States</td>
<td>0.60%</td>
<td>0.30%</td>
</tr>
<tr>
<td>9</td>
<td>Switzerland</td>
<td>0.44%</td>
<td>0.28%</td>
</tr>
<tr>
<td>10</td>
<td>Denmark</td>
<td>0.29%</td>
<td>0.28%</td>
</tr>
</tbody>
</table>

Note: (1) Market share of highway-capable electric-drive vehicles in the corresponding segment as percentage of total new car sales in the country in 2013.
...or is it a commodity?
the commodification of energy passes through ICT
How did we get here?
Morgan Mansion at Madison Ave. & 36th St., NYC.
Morgan Mansion at Madison Ave. & 36th St., NYC.  
1881
In 1881, Morgan's house became the world's first electrified residence, when Thomas Edison wired the structure with incandescent lights and installed a steam engine and dynamo in the back yard to provide power. The following year, Edison wired Morgan's office building, and for years Morgan was the primary investor in Edison's projects.
“every home, every factory and every transportation line will obtain its energy from one common source, for the simple reason that that will be the cheapest way to produce and distribute it”

-Samuel Insull (1859–1938)
and back?
Generation

Roof solar panel 125 W per module

Wind installation 1.4KW

Vaillant EcoPOWER 1.0 (Honda mCHP) 1KWe
Energy distribution
data generation potential
About a meter

0 bit/y
In The Netherlands 1 reading every two months

Assume 200 bytes per reading

9.600 bit/y
Messages could be bigger than 200 bytes, but let's disregard it for now.

1 reading every 15 minutes is likely.

42,075,888 bit/y
Appliances in the home are also getting smart...

Let's assume 20 smart appliances per home with 15 minutes readings

883,593,648 bit/y
You promised Green!

Renewable installations generate also data

Let’s assume 2 installations per home with 15 minutes reading

967,745,424 bit/y
What about storage?

Renewables are inconstant in generating, thus we will need storage.

Let's assume 1 battery set per home with 15 minutes reading.

1.009,821,312 bit/y
And mobility?

Let's assume a car per household, 0.75 eBikes/personal mobility per household.

Let's safely assume 1,000 bytes per day

1,014,931,312 bit/y
Weather information with km² precision and more

Social information

Social networks

Let's ignore this for now in our computation!

1.014.931.312 bit/y
8 million households

7,944,222,604,983,200 bit/y
No home is an island!

<table>
<thead>
<tr>
<th>Nodes HV (380/220kV)</th>
<th>36</th>
<th>1Mb/node/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nodes MV/LV</td>
<td>155,000</td>
<td>1Kb/node/h</td>
</tr>
<tr>
<td>Lines HV (380/220kV)</td>
<td>2.685 km</td>
<td>100 byte/km/h</td>
</tr>
<tr>
<td>Lines HV (50/110/150kV)</td>
<td>9.836 km</td>
<td>100 byte/km/h</td>
</tr>
<tr>
<td>Lines MV (3-25kV)</td>
<td>101.275 km</td>
<td>10 byte/km/h</td>
</tr>
<tr>
<td>Lines LV (0.4kV)</td>
<td>195.706 km</td>
<td>1 byte/km/h</td>
</tr>
</tbody>
</table>

7,957,780,320,747,680 bit/y
It’s a small world

X.XXX.XX7.957.780.320.747.68 bit/y
related research in Groningen
The Bernoulliborg, located on the Zernike Complex (Nijenborgh 9), is a new (2008) building of the University of Groningen.

**Floor area:** 12,000 / 8,295 Nett

**Number of staff:** 307

**Students capacity:** 500

**Number of offices:** 180

**Number of meeting rooms:** 8

**Number of lecture rooms:** 16

**Number of social corners:** 6

**Annual electricity consumption:**
- 1,396,276 kwh (2011)
- 1,359,821 kwh (2012)
User’s presence
User’s presence
User’s presence
Human in the loop

Service Composition layer

Ubiquitous System layer

Energy-aware Middleware
Event-based, Service-Oriented, Orchestrating

Actuation & Building Context Information

User interaction, control, feedback

Occupant behavior

Component interactions
User control
Ubiquitous Sensing

www.greenerbuildings.eu
1) Consumption measurement

Purpose:
Monitoring (and controlling) personal consumption

Location:
Bernoulli building, 5th floor

Scale:
12 areas (rooms)

Devices:
45 sensors
2) Consumption Display

**Purpose:**
Showing common electricity consumption

**Location:**
BB 5th floor, CS social corner

**Scale:**
1 location

**Devices:**
1 live-display (also available on web interface)
3) Computer Sleep solution

Purpose:
Monitoring and controlling PC consumption in a controlled environment

Location:
BB 5th floor

Scale:
1 lab
(next step, scaling-out to 200 rooms)

Devices:
10 PCs
(next step, scaling-out to 300 PCs)
4) Lighting control

**Purpose:**
Monitoring and controlling common consumption

**Location:**
BB restaurant at the ground floor

**Scale:**
1 large room

**Devices:**
30+ sensors/actuators
in turn affecting the distribution grid
Driving decisions:

1) Pricing Signals
2) Control from the infrastructure
3) Social pressure, sustainability
<table>
<thead>
<tr>
<th>Provider</th>
<th>Energy supply</th>
<th>Price per kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Wind Turbine</td>
<td>0.214292</td>
<td>0.0</td>
</tr>
<tr>
<td>Internal Solar Panel</td>
<td>0.302314</td>
<td>0.122916</td>
</tr>
<tr>
<td>COMED</td>
<td>2.755946</td>
<td>0.282973</td>
</tr>
<tr>
<td>ATSI</td>
<td>3.154828</td>
<td>0.357123</td>
</tr>
<tr>
<td>AEP</td>
<td>2.411659</td>
<td>0.360658</td>
</tr>
</tbody>
</table>

more providers ...  

Table 2: Example of energy providers and prices.
Real-time pricing related savings (~35%)
From the Grid’s point of view: a physical update is necessary?
Which synthetic network model is best?

1-modularity
2-quantitative metrics
3-thrift

<table>
<thead>
<tr>
<th>Network Model</th>
<th>Avg. node degree $&lt; k \approx 2$</th>
<th>Avg. node degree $&lt; k \approx 4$</th>
<th>Avg. node degree $&lt; k \approx 6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small-world</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Preferential Attachment</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Random Graph</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>R-MAT</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>
Example of evolution: least distance strategy
a very dynamic landscape
some examples
Turning **BIG DATA** into **POWER**

**BIG DATA** generated on the smart grid is growing exponentially.

How much money and electricity can be saved through better analytics and controls?

Quite a bit.

188 gigawatts or 20% of peak power can be provided by demand response by 2019.
Intelligent Electronic Devices

Unit Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>Units (millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>22</td>
</tr>
<tr>
<td>2020</td>
<td>175</td>
</tr>
</tbody>
</table>

Data Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>Data (petabytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
<td>368</td>
</tr>
</tbody>
</table>

CAGR 34%

1000 petabytes of data would be generated by smart meters if deployed universally in the U.S.

25% of electricity was saved by consumers using smart devices in time-of-use pricing programs.

Smart Meters

Unit Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>102</td>
</tr>
<tr>
<td>2020</td>
<td>512</td>
</tr>
</tbody>
</table>

Data Growth

<table>
<thead>
<tr>
<th>Year</th>
<th>Data (petabytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
<td>1076</td>
</tr>
</tbody>
</table>

CAGR 26%
8330 Libraries of Congress worth of data is contained within 1000 petabytes

**Demand Response**

- **Demand Response / Dynamic Pricing**
  - 2013: 11.1 (customers, millions)
  - 2020: 21.2 (customers, millions)
  - CAGR: 10%

- **Peak Load Reduction from DR**
  - 2013: 4500 (megawatts)
  - 2020: 8200 (megawatts)
  - CAGR: 9%

- **World Wide**
  - 2013: 13.1 (customers, millions)
  - 2020: 28.3 (customers, millions)
  - CAGR: 12%

- **Peaker Plants**
  - 2000 peaker plants producing 75MW each could be eliminated with 150GW demand response in the US
Electric Vehicles

Unit Growth

- 2013: 0.08 (units, millions)
- 2020: 4.4 (units, millions)

Data Growth

- 2013: 1 (data, petabytes)
- 2020: 36 (data, petabytes)

CAGR 77%

- 2013: 0010100
- 2019: 1000010
- 2020: 0110010
- 2001011

CAGR 87%

- 2013: 000101
- 2019: 001000
- 2020: 010101
- 001010

$34 billion will be invested in smart grid analytics by 2020.
$34 billion will be invested in smart grid analytics by 2020.

### Analytics

**Value of Analytics**
- CAGR: 19%

**Annual ROI to Customer**
- CAGR: 25%
Analytic Value

Value of Analytics

<table>
<thead>
<tr>
<th>Year</th>
<th>USD (billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>$0.5</td>
</tr>
<tr>
<td>2020</td>
<td>$1.7</td>
</tr>
</tbody>
</table>

Annual ROI to Customer

<table>
<thead>
<tr>
<th>Year</th>
<th>USD (billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>$1.4</td>
</tr>
<tr>
<td>2020</td>
<td>$6.6</td>
</tr>
</tbody>
</table>

CAGR Growth:

- Value of Analytics: 19%
- Annual ROI to Customer: 25%
- 2013: $1.1 billion, 2020: $4.8 billion (23% CAGR)
- 2013: $2.4 billion, 2020: $16.8 billion (32% CAGR)

Note: This is self-collected data. It does not include back-ups, billing data created from it, and reporting data created.
# The Data Deluge in the Energy Industry

<table>
<thead>
<tr>
<th># of meters</th>
<th>15 minute interval (per year)</th>
<th>1 minute interval (per year)</th>
<th>1 second interval (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>31.9 GB</td>
<td>467 GB</td>
<td>28.0 TB</td>
</tr>
<tr>
<td>100,000</td>
<td>319 GB</td>
<td>4.67 TB</td>
<td>280 TB</td>
</tr>
<tr>
<td>1,000,000</td>
<td>3.19 TB</td>
<td>46.7 TB</td>
<td>2.80 PB</td>
</tr>
</tbody>
</table>

- **Increasing Granularity of Data**
- **Unprecedented Levels of Data**

- Y2E2 Building @ Stanford
- 1 Year
- 2,600 points
- 1 min reads
- 100 GB

- 1,000 Y2E2 Buildings @ 1 second intervals

6 Petabytes = the entire US Library of Congress X 50!
Office buildings and data centers?

http://youtu.be/e-ZqVqS7uiM
the commodification of energy passes through ICT
Thank you
Thank you


