This is exactly what I had in mind. It's perfect.

On page 6, there is a Super grid box, could you try to create a similar one, but only with skyscrapers in the circles, and maybe some antenna and computer?
Introduction to Smart Grids

Beyond smart meters

Smart-grid technologies have the potential to address today’s grid challenges, including rising electricity demand, aging infrastructure, and the increasing penetration of variable and distributed energy sources in the supply mix. Numerous innovations can already contribute to the modernization of electricity networks. They aim to: enable the use of all generation and storage options; optimize energy efficiency and asset utilization; improve power quality for end-user devices; self-heal; resist physical and cyber attacks; and enable new business solutions in a more open-access electricity market. But social acceptance, cybersecurity, regulation, and international collaboration on standardization and best practices are vital to successful deployment.

The content of this summary is based upon the FactBook “Introduction to Smart Grids”

For the complete FactBook and other FactBooks by the A.T. Kearney Energy Transition Institute, please visit www.energy-transition-institute.com.
Electricity grids need to be modernized to meet growing demand and integrate new applications.

Century-old by design, today’s grids were built to accommodate centralized generators, unidirectional electricity transport through high-voltage transmission lines, dispatch to consumers via lower-voltage distribution feeders, and centralized control centers collecting information from a limited number of network hubs, called substations. The goal of such power grids is to optimize, for a given combination of power plant fleets and consumer-demand pattern, both reliability (the frequency and extent of outages) and quality of power supplied (in terms of voltage signal shape, frequency and phase angle) at a minimal cost.

Today’s grids are facing four principal problems and these are growing in severity:

First, electricity demand is rising faster than demand for any other form of final energy globally (2% per year until 2040), and intensifies around peak times because of the progressive shift in consumption from a steady industrial baseload to variable household and commercial demand. As a result, grids are being increasingly stressed, making rapid expansion a necessity.

Second, aging infrastructure tends to compromise the reliability of power supply and exacerbate energy losses to the detriment of economies undergoing rapid electrification. In India, inadequate distribution networks result in the loss of 20% of transmitted electricity, while, in the U.S., aging transmission network is causing a decline in the reliability of power supply.

Third, as the share of Variable Renewable Energy (VRE) in the energy mix grows, the power grid will need to become more flexible to match supply and demand in real time.

Finally, as the penetration of Distributed Generation (DG) rises to very high levels in some areas, issues relating to power quality and bi-directional electricity flows arise that cannot be properly managed by traditional grids.

The need for grid modernization differs from country to country, depending on the state of the existing transmission & distribution (T&D) infrastructure, generation capacities and demand patterns.

Power grids, which bring electricity to 85% of the world’s population, are arguably one of the most important engineering achievements of the 20th century.
A smart grid refers to a modernized electricity network that monitors, protects, and optimizes the operation of its interconnected elements.

A smart grid is generally characterized by the use of digital information and communications technologies to manage both the bi-directional flow of data between end-users and system operators, and the bi-directional flow of power between centralized and decentralized generation.

The goal of these modernized networks is to address previously identified grid challenges at a minimal cost. To fulfill this purpose, grids must be able to accommodate all generation and storage options, optimize energy efficiency and asset utilization, improve power quality for end-user devices, self-heal, resist physical and cyber attacks, and enable new business solutions in a more open-access electricity market, such as demand-response programs and virtual power plants.

Beyond incremental changes in traditional grids, smart grids facilitate the expansion of independent micro-grids that are capable of “islanding” themselves from the main grid during power-system disruptions and blackouts. The modular nature of micro-grids may allow for their independence, interconnection and, ultimately, the construction of a new type of super-reliable grid infrastructure.

### Figure 2. Simplified view of the modernized grid

<table>
<thead>
<tr>
<th>Area</th>
<th>Traditional grid</th>
<th>Smart grid</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication</strong></td>
<td>Electromechanical</td>
<td>Digital</td>
</tr>
<tr>
<td></td>
<td>One-way</td>
<td>Two-way</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Centralized</td>
<td>Centralized &amp; distributed</td>
</tr>
<tr>
<td></td>
<td>Few sensors</td>
<td>Sensors throughout</td>
</tr>
<tr>
<td></td>
<td>Manual monitoring</td>
<td>Self-monitoring</td>
</tr>
<tr>
<td></td>
<td>Manual restoration</td>
<td>Self-healing</td>
</tr>
<tr>
<td></td>
<td>Failures and blackouts</td>
<td>Adaptive &amp; islanding</td>
</tr>
<tr>
<td></td>
<td>Limited control</td>
<td>Pervasive control</td>
</tr>
<tr>
<td><strong>Market</strong></td>
<td>Few customer choices</td>
<td>Many customer choices</td>
</tr>
</tbody>
</table>

The transition to a smart grid requires the deployment of new technologies, which can be segmented into three main categories of application.

The transition to a smart grid requires the deployment of new power infrastructure, electronic devices and computer systems, interconnected via high-speed communications networks, using standardized protocols. This FactBook covers the most important smart-grid technologies, which can be segmented into three main categories of application.

The first application involves the optimization of grid monitoring and control, with advanced sensors and IT solutions interconnected via modern communications networks in Wide-Area Monitoring & Control (WAMC) or Distribution Automation (DA) systems. Such systems enhance control over dispatchable power plants; improve routing of electricity flows; anticipate demand patterns or grid weaknesses by virtue of predictive algorithms and condition-based maintenance; react automatically to incidents threatening the reliability of power supply with the use of smart reclosers, which make distribution grids self-healing.

The second purpose of smart grids is to enable consumers to contribute to grid management through the medium of intelligent end-user devices. Combining advanced metering infrastructure with smart appliances makes dynamic demand-response programs possible. These can contribute to system flexibility (in addition to peaking power plants or electricity storage) to compensate for fluctuations in VRE output or to flatten out aggregated peak loads. Bi-directional smart meters enable net metering and vehicle-to-grid programs and sensors that incentivize individual customers to become local suppliers of power and storage capacity. In addition, automated meter readings reduce the operating costs of distribution-system operators and provide greater visibility into pilferage.

The third principal aim of smart-grid technology is to enhance the physical capacity of the network. Ultra-high voltage lines, direct-current underground cables or superconductors transport more power with lower energy losses and a smaller visual footprint than conventional power lines. These new technologies could be especially effective in connecting remote offshore wind farms to distribution grids or interconnecting asynchronous grids. Finally, the maximum admissible power throughput of existing lines could also be dynamically enhanced by installing along them special temperature sensors, voltage or current control devices. This would allow the deferral of expensive and sometimes-controversial grid-extension plans.

### Figure 3. Smart-grid technologies by application and device type

<table>
<thead>
<tr>
<th>Type of device</th>
<th>Main stakeholders</th>
<th>Generation (Utilities, cooperatives, end users...)</th>
<th>Transmission</th>
<th>Distribution</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication networks</td>
<td>Micro-Grids and Smart Cities</td>
<td>(no transmission)</td>
<td>Micro-Grids and Smart Cities</td>
<td>Field Area Network (FAN)</td>
<td>Home Area Network (HAN)</td>
</tr>
<tr>
<td>Electric-power infrastructure</td>
<td></td>
<td>Wide Area Network (WAN)</td>
<td>High Voltage Direct Current (HVDC), Superconductors</td>
<td>Smart Switches</td>
<td>Vehicle-to-Grid (V2G)</td>
</tr>
<tr>
<td>Electronic devices and sensors</td>
<td></td>
<td>Dynamic Line Rating (DLR)</td>
<td>Flexible AC Transmission Systems (FACTS)</td>
<td>Capacitor Banks</td>
<td>Smart Inverters</td>
</tr>
<tr>
<td>Systems and processes</td>
<td></td>
<td>Advanced Metering Infrastructure (AMI, Smart meters, MDMS...)</td>
<td>Fault Current Limiters (FCL)</td>
<td></td>
<td>Smart Appliances and In-Home Display (IHD)</td>
</tr>
<tr>
<td><strong>Technology application</strong></td>
<td></td>
<td>Optimize grid monitoring and control</td>
<td>Enhance physical network capacity</td>
<td>Enable active customer contribution</td>
<td></td>
</tr>
</tbody>
</table>

Note: Numerous technologies have been deliberately excluded from the scope of this report for the purposes of simplification. Segmentation by application is only indicative. Overlaps exist, and smart-grid technologies only offer maximal benefits when integrated together.

Source: A.T. Kearney Energy Transition Institute analysis
Figure 4. Key smart-grid technologies covered in the FactBook

- **Wide-Area Monitoring & Control**
  - “Self-healing”
  - Energy Management Systems (EMS)
  - Wide Area Protection & Communications Network

- **Superconductors**
  - “0 resistance - 0 losses”
  - “Classic” Conductor vs. Superconductor

- **HVDC**
  - “Direct Current”
  - AC vs. DC

- **Dynamic Line Rating**
  - “Adapt to the weather”
  - Cool, windy, cloudy vs. hot, calm, sunny

- **Vehicles-to-Grid**
  - “Plug in to the grid”
  - “Sell your surplus”

- **Net Metering**
  - “Bi-directional & real time”
  - PMU

- **PMU**
  - “Synchronized sensor”

- **Distribution Automation**
  - Optimize grid monitoring and control via ICT systems, sensors, and power electronics

- **Predictive Algorithms**
  - “Forecast demand, prevent failure”

- **FACTS, VVC, SVC**
  - “Maintain power quality”

- **CVR**
  - “Conserve voltage, save energy”

- **Fault Current Limiter**
  - “Absorb electric shock”

- **Super-Grid**
  - “Interconnected micro-grids”

- **Enable active customer contribution**

Source: A.T. Kearney Energy Transition Institute
## Smart-grid benefits by technology application and related grid challenges

<table>
<thead>
<tr>
<th>Existing grid challenges</th>
<th>Enhance physical network</th>
<th>Optimize grid monitoring &amp; control</th>
<th>Enable active customer contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rising and intensifying electricity demand</strong></td>
<td>Increase power-line capacity via electronic devices and sensors installed along the lines (DLR, FCL, FACTS, CVR…)</td>
<td>Predict and optimize electricity flow via new sensors and algorithms of higher spatial and temporal granularity, and Wide-Area Monitoring &amp; Control (WAMC, PMU…)</td>
<td>Flatten aggregated peak demand via dynamic demand-response programs</td>
</tr>
<tr>
<td><strong>Aging infra-structure (losses &amp; unreliability)</strong></td>
<td>Reduce transport losses by using more efficient cables (HVDC, superconductors…)</td>
<td>Improve power reliability via smart protection systems, both in anticipation (failure prediction algorithms and condition-based maintenance), and in reaction (distribution automation, self-healing grid, FDIR)</td>
<td>Track down thefts via advanced metering infrastructure</td>
</tr>
<tr>
<td><strong>Increasing share of Variable Renewable (VRE)</strong></td>
<td>Connect offshore wind-farms via subsea HVDC cables</td>
<td>Smooth variability of VRE output by enlarging grid inter connections via Wide-Area Monitoring &amp; Control</td>
<td>Provide additional flexibility means by pooling of customers into virtual power plants that can store or supply large amounts of electricity in a dispatchable manner</td>
</tr>
<tr>
<td><strong>Increasing share of Distributed Generation (DG) &amp; Electric Vehicles (EV)</strong></td>
<td>Achieve customer energy savings by stabilizing voltage delivered to end-users as closely as possible above nominal values, optimizing appliance efficiency (CVR)</td>
<td>Preserve power quality by absorbing voltage instability caused by back-flows of electricity or re-synchronization of islanded micro-grids thanks to voltage control (VVC, capacitor banks, PMU…)</td>
<td>Incentivize DG and EV deployment via net metering programs and vehicle-to-grid technologies, which turn individual customers into local suppliers of electricity</td>
</tr>
</tbody>
</table>

Source: A.T. Kearney Energy Transition Institute

---

Smart-grid technologies have the potential to answer numerous grid challenges, and achieve their best efficiency when integrated altogether.
Smart grids promise numerous economic and environmental benefits, provided social acceptance and cybersecurity issues are thoroughly addressed.

**Economic impacts.** It is estimated that a smart-grid roll-out would generate net economic and environmental benefits in all regions where studies have taken place, although impacts are difficult to quantify. The U.S. Electric Power Research Institute (EPRI) estimates that the benefits for U.S. society as a whole would outweigh its costs by a factor of between 2.7 and 6. Restricting the scope to electricity-grid stakeholders, the International Energy Agency (IEA) estimates the ratio to be between 2 and 4 in OECD countries, and between 3 and 4.5 in China.

**Environmental benefits.** Although environmental sustainability is not the primary driver behind the adoption of smart grids, they help limit greenhouse-gas emissions both directly (through energy savings) and indirectly (by encouraging the development of electric vehicles and renewables). The IEA estimates that smart grids could contribute to 4% of cumulated CO2 emissions-reduction efforts by 2030, in the lowest-cost pathway towards the 2°C target.

**Societal impacts.** The concept of a smart grid relies to a large extent on active consumer participation and, for this reason, requires social acceptance. As future electricity grids will collect, communicate and store operational and private data, the issues of cybersecurity, data protection and data sharing must be carefully addressed.
Smart-grid technologies are attracting investor interest, but proper regulation and collaboration in standardization and best practices are vital to successful deployment

Global annual investments in electricity grids amounted to $218 billion in 2014 and are growing by 4% a year. Smart-grid technologies currently represent 20% of these investments ($44 billion), or $16 billion if the scope is restricted to digital energy technologies. Smart-grid investments are expected to grow by 5% a year until 2020, led by digital energy (9% a year), due in particular to rapid smart-meter roll-out: 100 million units were installed in 2014, and the penetration rate globally is set to increase from 22% to 40% in 2020.

Private investors’ interests in smart-grid RD&D intensified after 2008, following announcements of support from the U.S. DOE ($4.5 billion committed), and EU (€3 billion already allocated). Although raised funds have stabilized since 2011, venture capitalists remain highly interested in digital-energy technologies, which are among the most sought-after clean-energy investments – only just behind solar PV in terms of numbers of deals in 2014.

If smart-grid investments are mostly borne by system operators, benefits are spread among many parties (including customers and all citizens, if environmental benefits are taken into account). Yet, as electricity markets evolve through the unbundling of monopolies, the design of smart-grid business models is becoming more complex. Therefore, carefully planned regulatory frameworks are required to encourage smart-grid roll-outs. Finally, standards covering interoperability, compatibility and industry best practice are among the most crucial prerequisites for smart-grid deployment, in avoiding the premature obsolescence of smart-grid devices.
Conclusion

Electrons are the fastest-growing energy carrier and a pivotal element of the transformation of the energy system. Economies will become increasingly dependent on electricity, as renewable energy expands and environmental concerns intensify. As a result, electricity networks are being rapidly modernized through the introduction of smart-grid technologies. This is enabling growth in power-generation capacity, as well as the integration of new energy sources and shifts in consumer behavior.

About the A.T. Kearney Energy Institute

The A.T. Kearney Energy Transition Institute is a nonprofit organization. It provides leading insights on global trends in energy transition, technologies, and strategic implications for private sector businesses and public sector institutions. The Institute is dedicated to combining objective technological insights with economical perspectives to define the consequences and opportunities for decision makers in a rapidly changing energy landscape. The independence of the Institute fosters unbiased primary insights and the ability to co-create new ideas with interested sponsors and relevant stakeholders.

Acknowledgements

A.T. Kearney Energy Transition Institute wishes to acknowledge for their review of this FactBook:
Dr. Mohamed A. El-Sayed, Professor Electrical Department at College of Engineering and Petroleum, Kuwait University; Professor Anna Creti, Université Paris Dauphine, Senior Research Fellow at Ecole Polytechnique, Visiting Research Fellow at University of California Berkeley; Professor & Director Rajit Gadh, UCLA WINMEC & Smart Grid Energy Research Center; Jacqueline Chia, Senior Assistant Director Energy Division (Energy Market) at Ministry of Trade & Industry, Singapore. The Institute also wishes to thank the authors of this FactBook for their contribution: Bruno Lajoie, Romain Debarre, Yann Fayet and Gautier Dreyfus.

For further information about the A.T. Kearney Energy Transition Institute and possible ways of collaboration, please visit www.energy-transition-institute.com or contact us at contact@www.energy-transition-institute.com.