



ECONOMICS OF MODERN POWER SYSTEMS

M2 - SG: How Electricity Distribution will Change?

Learning Goals



- ▣ Smart Meters
- ▣ ICT Perspectives
- ▣ The End User View
- ▣ The Utility/Distribution System Operator View
- ▣ Experiences from Smart Meter Deployment



Smart Meters

Smart Meters deployment is the first stage of Smart Grid implementation



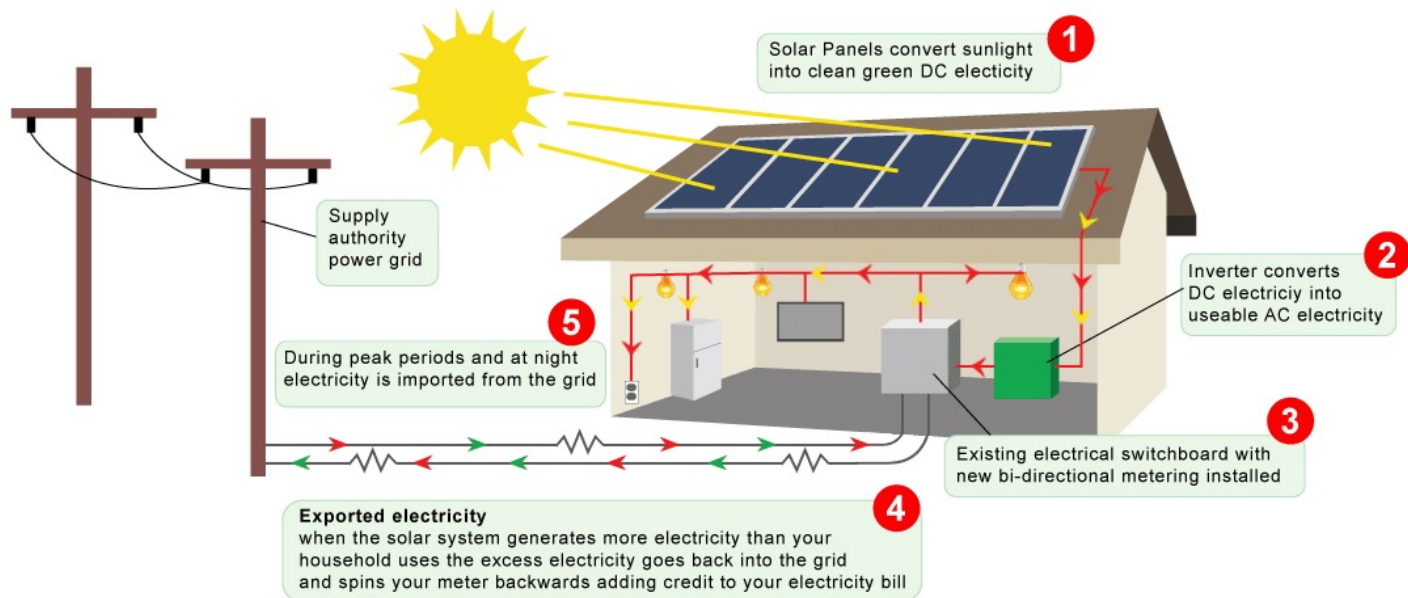
History of electricity meters

- Traditional meters
 - ▣ Mechanic analog devices
 - ▣ “Black boxes” rotating as current went through them
 - ▣ **Physically** inspected monthly or sometimes yearly for billing purpose
 - ▣ Patent of 1889 of the Hungarian Otto Blathy
 - ▣ Survived a century and are still widely used



So why change now?

- Energy flows have become bi-directional
 - ▣ The meter has to account for electricity fed back into the grid and not only coming from it



- Current trends toward clean energy and need to improve energy efficiency

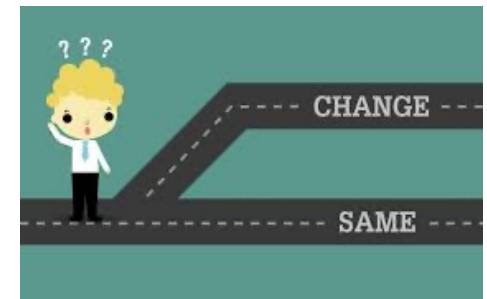
New meters: Smart meters

- Electronic meters with ability to expose its state via wired or wireless communication channels
- No need to physically access it to look at the number reported
- Possibility of **reading it remotely** and as frequently as needed
- New role for meter
 - ▣ Device that can help predict electricity consumption precisely
 - ▣ Real-time view of consuming/producing at any node of the grid

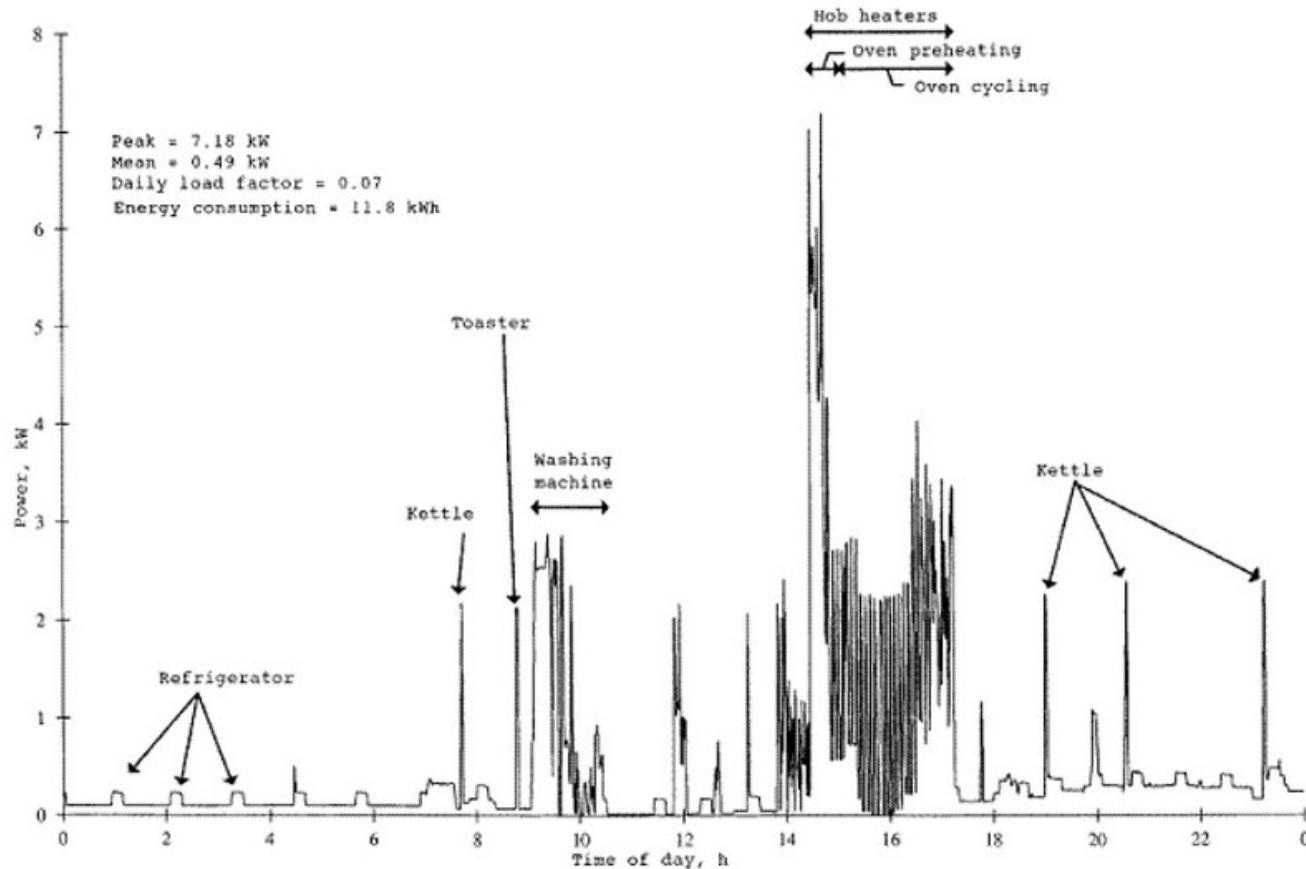


New meters: Smart meters

- Large amount of data for energy use
 - ▣ Utilities can better manage their assets
 - ▣ Better plan their infrastructure based on actual usage and not only peak estimation
- New meter will be able to react to signals in combination with intelligent appliances
- They will help users understand how they use their energy and change their behavior



Appliance load signature



IEEE Spectrum, "Are smart meters spies? They don't have to be",
<http://web.archive.org/web/20130728041904/http://spectrum.ieee.org/energy/the-smarter-grid/privacy-on-the-smart-grid>

Downside of Smart Meters

- Job loss - technologies putting people out of work
- Radiation
 - ▣ Collected data is sent a few times per hour
 - ▣ Radiate several electromagnetic frequency pulses each minute
- Invasion of privacy
 - ▣ Smart meters can differentiate between electric usage of coffee pot, microwave or TV
 - ▣ Utility can send this information to these appliance companies so they can better market them
- Utilities will be able to remotely turn off your appliances
- [“Take Back Your Power”](#) documentary by Josh de Sol

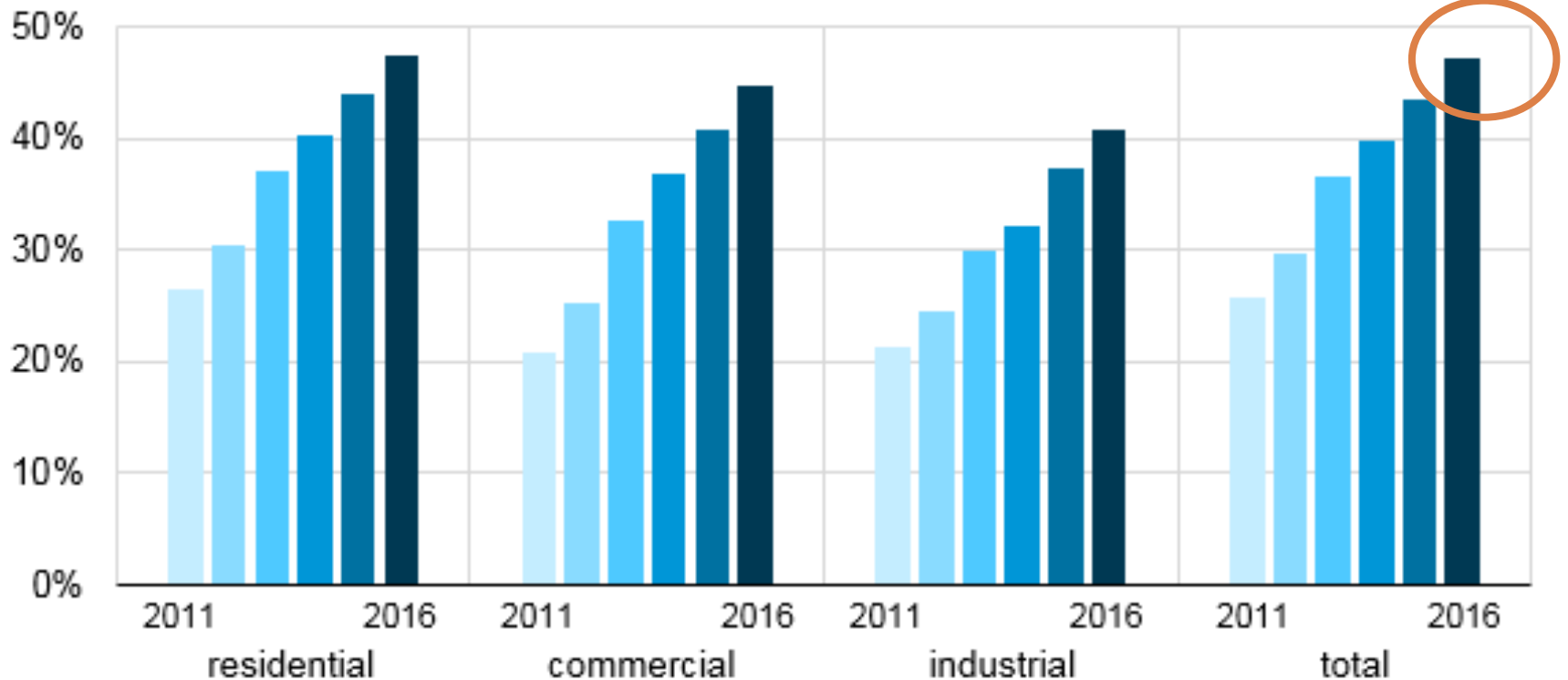
Smart meters deployment in US

- How many smart meters are installed in the US, and who has them?
 - ▣ In 2016, U.S. electric utilities had about **70.8 million** advanced (*smart*) metering infrastructure (AMI) installations
 - ▣ About **88%** of the AMI installations were **residential customers**
 - ▣ AMI includes meters that measure and record electricity usage at a minimum of hourly intervals and that provide the data to both the utility and the utility customer at least once a day
- Good source of information: Smart Electric Power Alliance (SEPA)

<https://sepapower.org>

Nearly half of US electricity customers have smart meter

Smart electricity meter installations (2011-2016)
percent of sector total

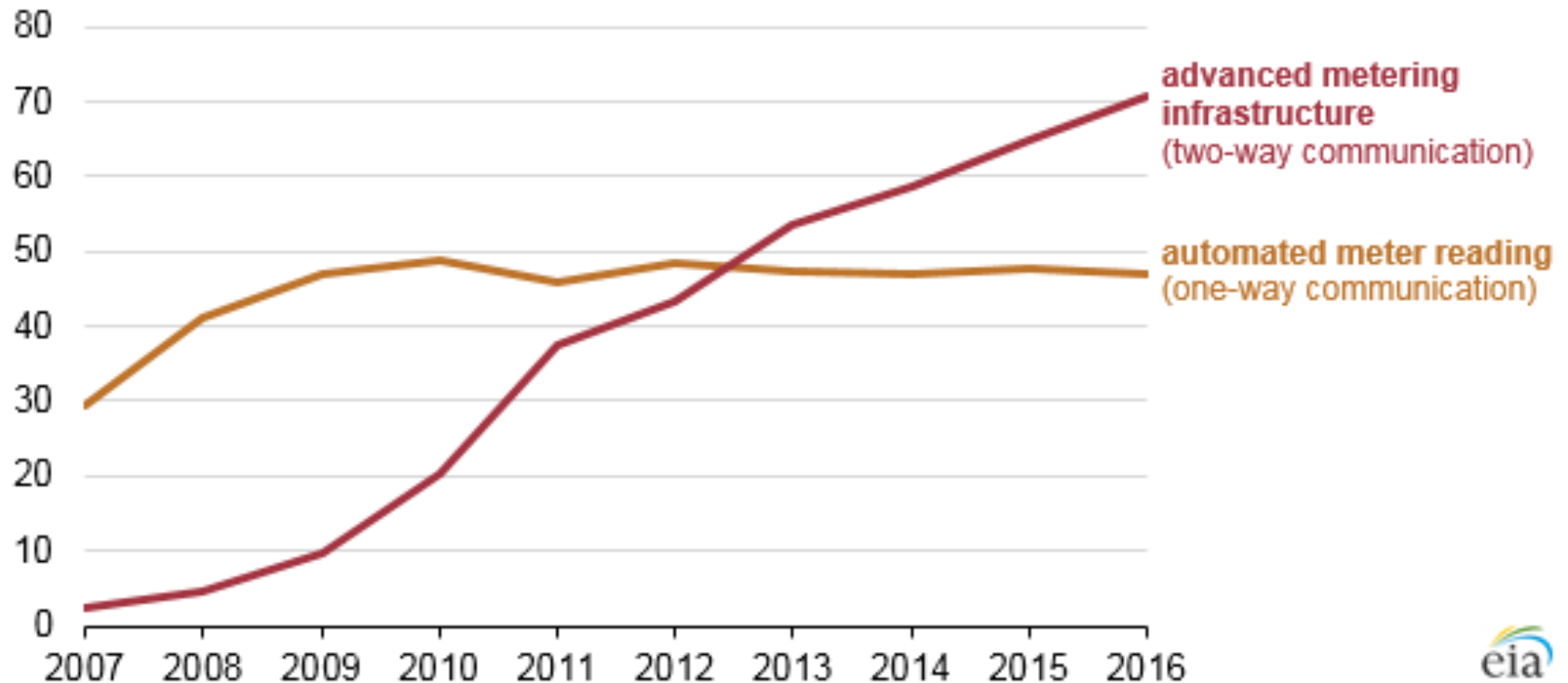


End of 2016: 47% of the 150 million customer in the US with
AMI

Smart meter adoption shift

U.S. advanced electric utility meter adoption (2007-2016)

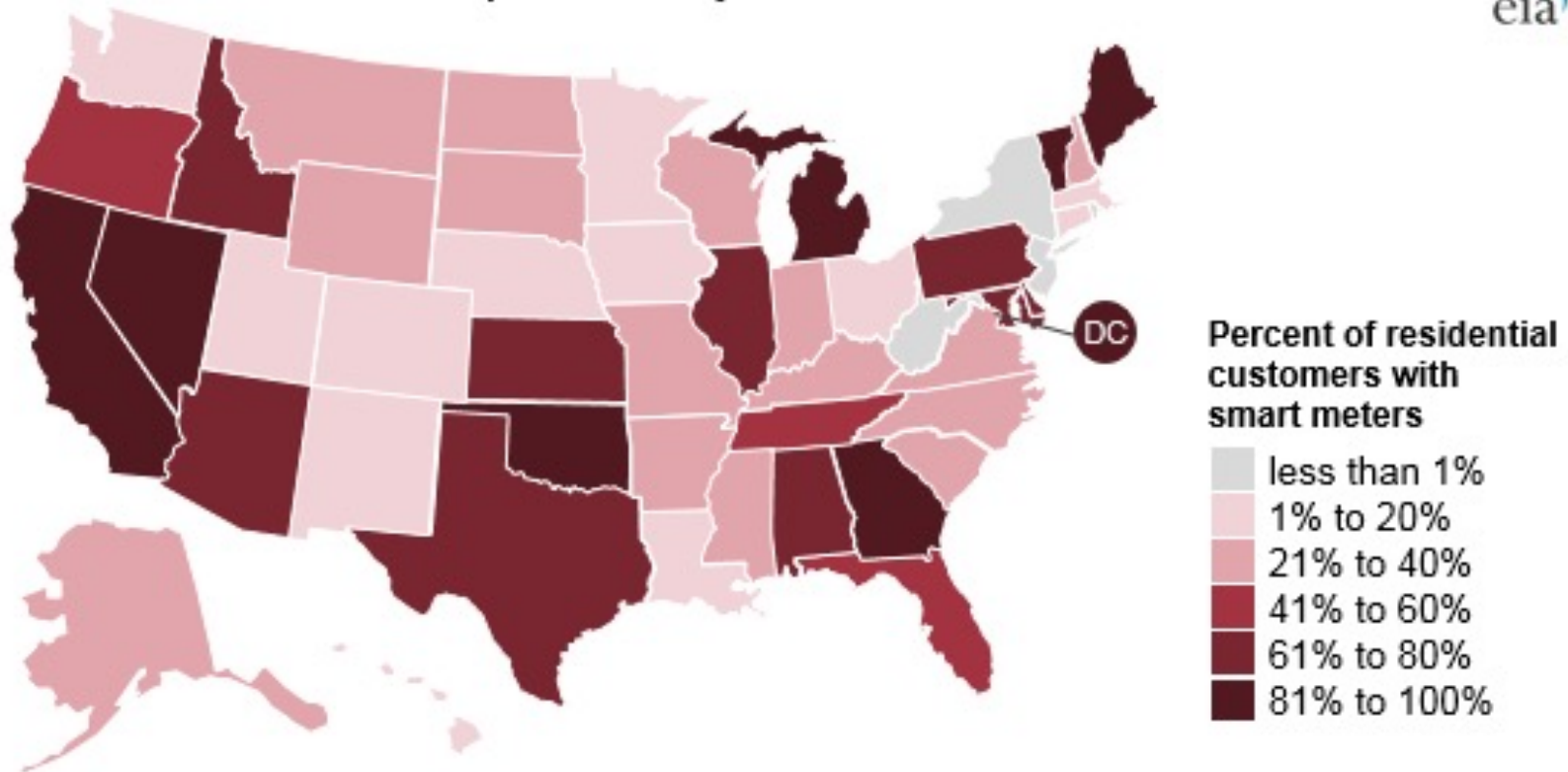
millions of customers



AMRs were more common before 2013, later shift to AMIs

Smart meter adoption rate by state, 2016

Residential smart meter adoption rates by state, 2016



Smart meter penetration varies widely by state due to state legislation and regulation

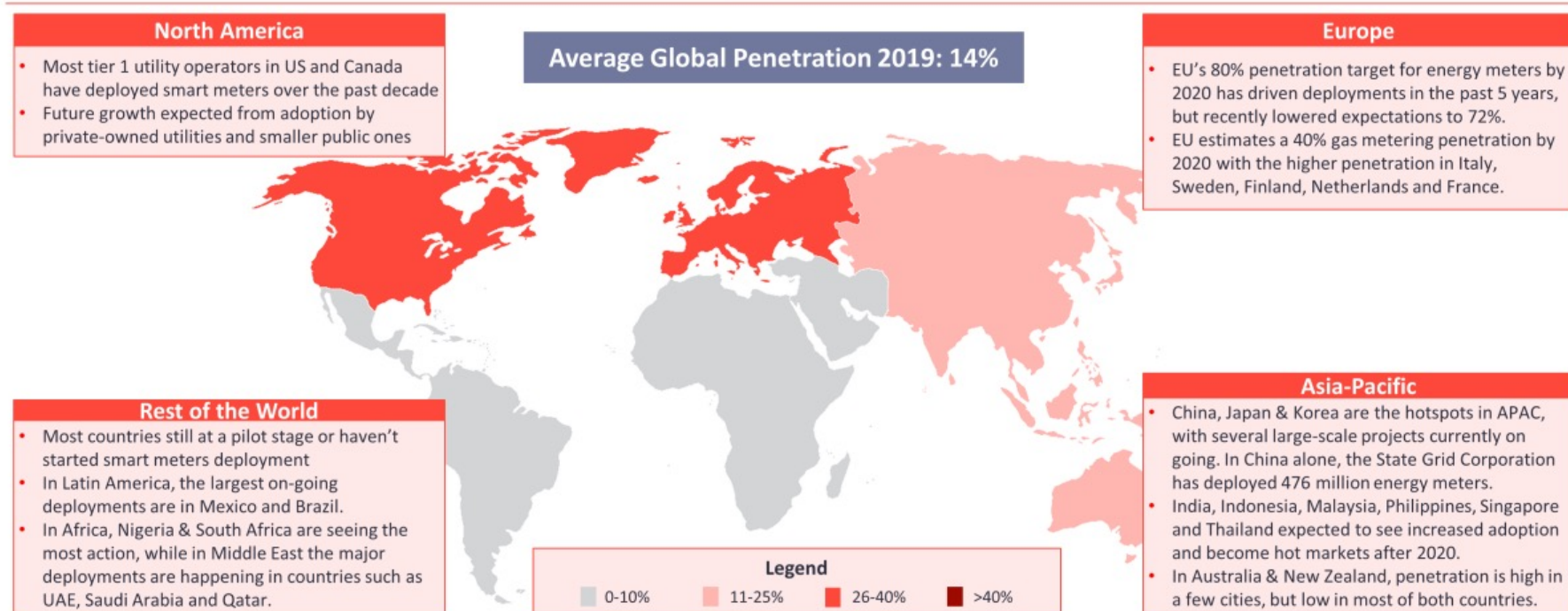
- DC has the highest rate at 97%, followed by Nevada at 96%
- Maine, Georgia, Michigan, Oklahoma, California, and Vermont – over 80%

Smart Meter Deployment World

- China continues to lead the global smart meter market with 496 million installations during Q1 of 2018
- Full scale or high volume rollouts continue in Japan and South Korea
- India has been slow in implementing its country-wide smart meter program
- Installation in Eastern Europe, Latin America, the Middle East and Africa has occurred in various small and medium scale deployments

Global Smart Meter Deployment

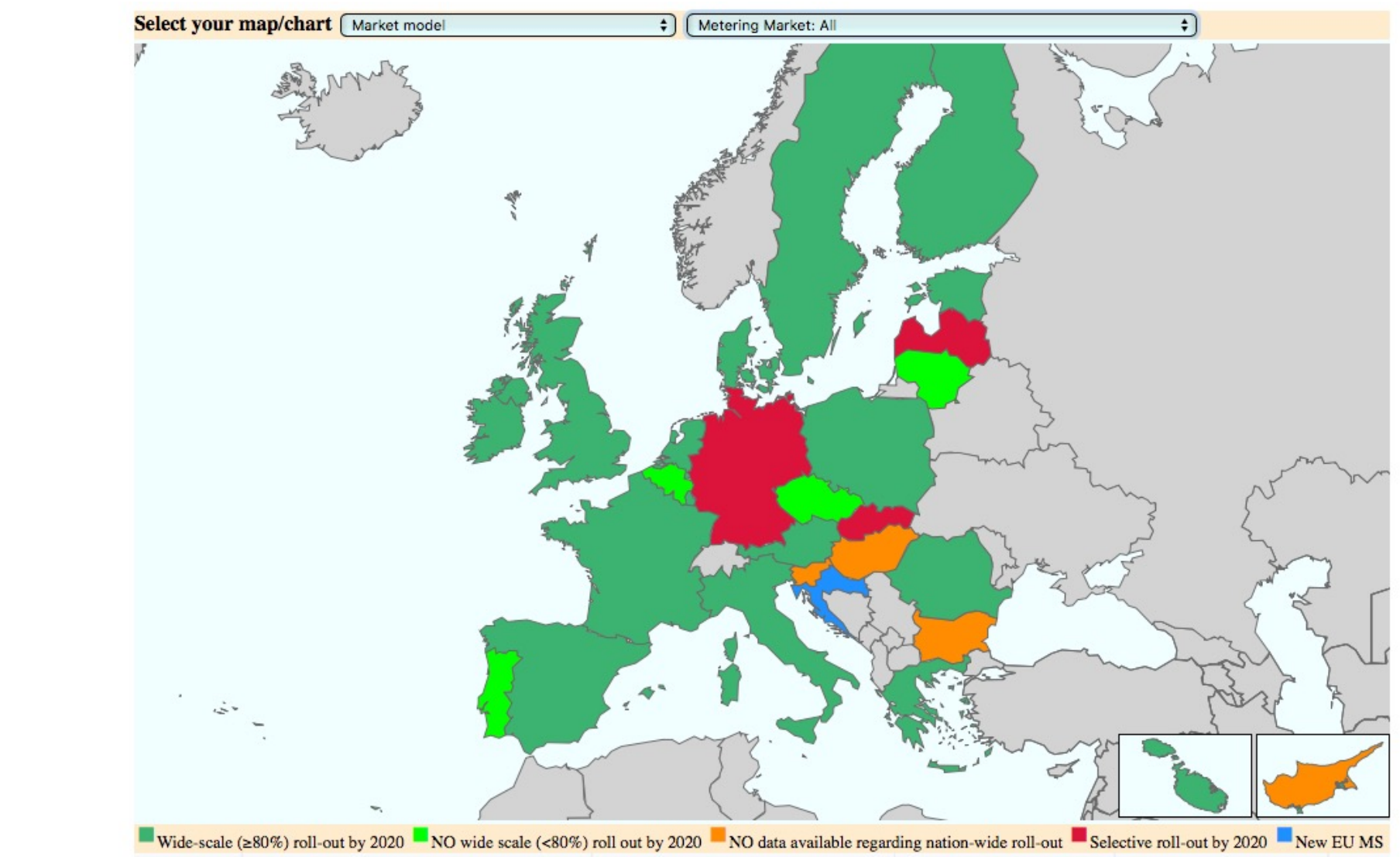
Global Smart Meter Penetration by region 2019



Definition: Smart meters are defined as intelligent, network-enabled measuring systems for resources and energy such as water, gas or electricity that use computer-aided measurement, determination and control of consumption and supply for residential, commercial and industrial buildings; as opposed to traditional standalone analog-based meters which do not have the ability to wirelessly send meter readings.

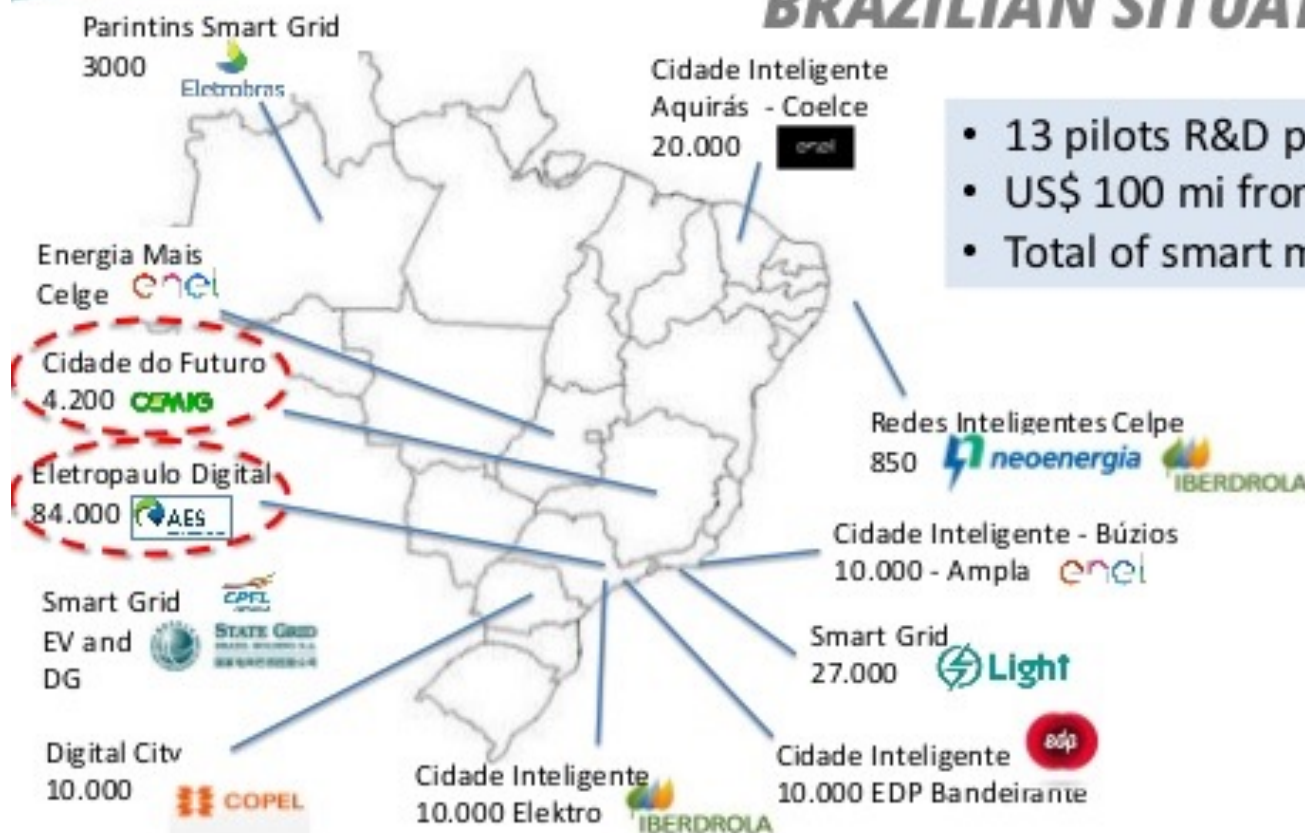
Note: Smart meter penetration indicates how many of all the meters (including electricity, water, gas meters but excluding submetering or heat meters) installed by end of 2019 are smart, e.g. 20% penetration rate means 1 every 5 meters is smart. Global penetration rate is calculated as the share of smart meters divided by all meters.

Source: IoT Analytics Research 2019



Smart Meter Deployment Brazil

THE SMART GRID DEPLOYMENT: CURRENT BRAZILIAN SITUATION



- 13 pilots R&D projects
- US\$ 100 mi from Aneel Funds
- Total of smart meters: almost 200.000



Information & Communication (ICT) Perspective

ICT role in electric distribution systems

- Consequences of bi-directional electricity flows
 - “**electricity meter** has to transform in such a way that it can help **predict electricity consumption** and can **deliver a real-time view of both production and consumption** anywhere in the distribution grid”
- Two constraints

ICT R&D must deal with a material **infrastructure** that is highly **constrained** by **physical laws**

Power systems R&D faces the challenge of having to **decentralize its operations** and to make room for **decision-making** by **more active end-users**

ICT Perspective

- Smart meters communicate their readings on a regular basis
 - ▣ Telecommunication infrastructure and information system to manage the data
- More accurate predictions of energy consumption per year
 - ▣ Useful to have historical readings of meter with granularity of minutes
 - ▣ More accurate recognition of which appliances are running
 - ▣ **Correlations with weather and calendar information to estimate load**

Issues: amount of data, speed and usefulness

□ Volume

- Netherlands example
- Shift from GB to PB of information
1 PB = 1,000,000 GB

Table 1 Scenario of data generation related to the smart grid for the Netherlands.
Source Aiello (2014)

<i>Metering</i>	
Metered customers	9,000,000
Installed smart meters	9,000,000
Smart meter sampling period (min)	5
<i>Smart devices</i>	
Electric vehicles	3,950,000
Battery packs	135,000
Intelligent appliances per household	20
<i>Grid infrastructure</i>	
Nodes HV (380/220 kV)	60
Nodes MV/LV	178,221

□ Velocity

- Existing infrastructure such as the Internet would not be sufficient to satisfy bandwidth and response time needed
- Filtering and aggregation might be required

□ Value

- Large amounts of data brings no specific benefit
- Information that reside in the data will give additional value and open new possibilities

Energy Analytics



The End User View

How to engage end-users?

- End-users are used to being able to use electricity whenever they want
- Need to engage them in smart energy behavior
 - ▣ energy efficiency
 - ▣ flexibility
 - ▣ Sustainable energy generation
- Challenges
 - ▣ Identifying and targeting specific end-user groups
 - ▣ Hard to “sell” – find innovative product with clear added value



For more information:

<https://pdfs.semanticscholar.org/53c3/a56b0b5e088fd0a62fafb20fe5118b3e4a62.pdf>

Shift in User Perspective

- Past: very limited knowledge of how energy was used
- Today: users can finally understand their energy footprint, resort automation and make conscious decisions based on real-time information



You Can See What's in Your Fridge While Grocery Shopping

They Have Alexa Built-In, Which Is Handy in the Kitchen

Think about smart TVs!

Nest thermostats start learning about your system and your home right away

Learn temperatures you like, your schedule!

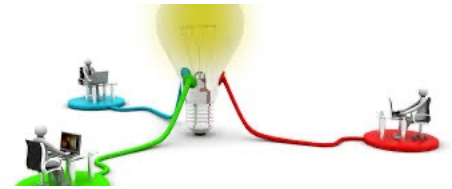
When you leave the house, the Nest Thermostat will automatically set itself to an Eco Temp to save energy



You can do that already, but do you?

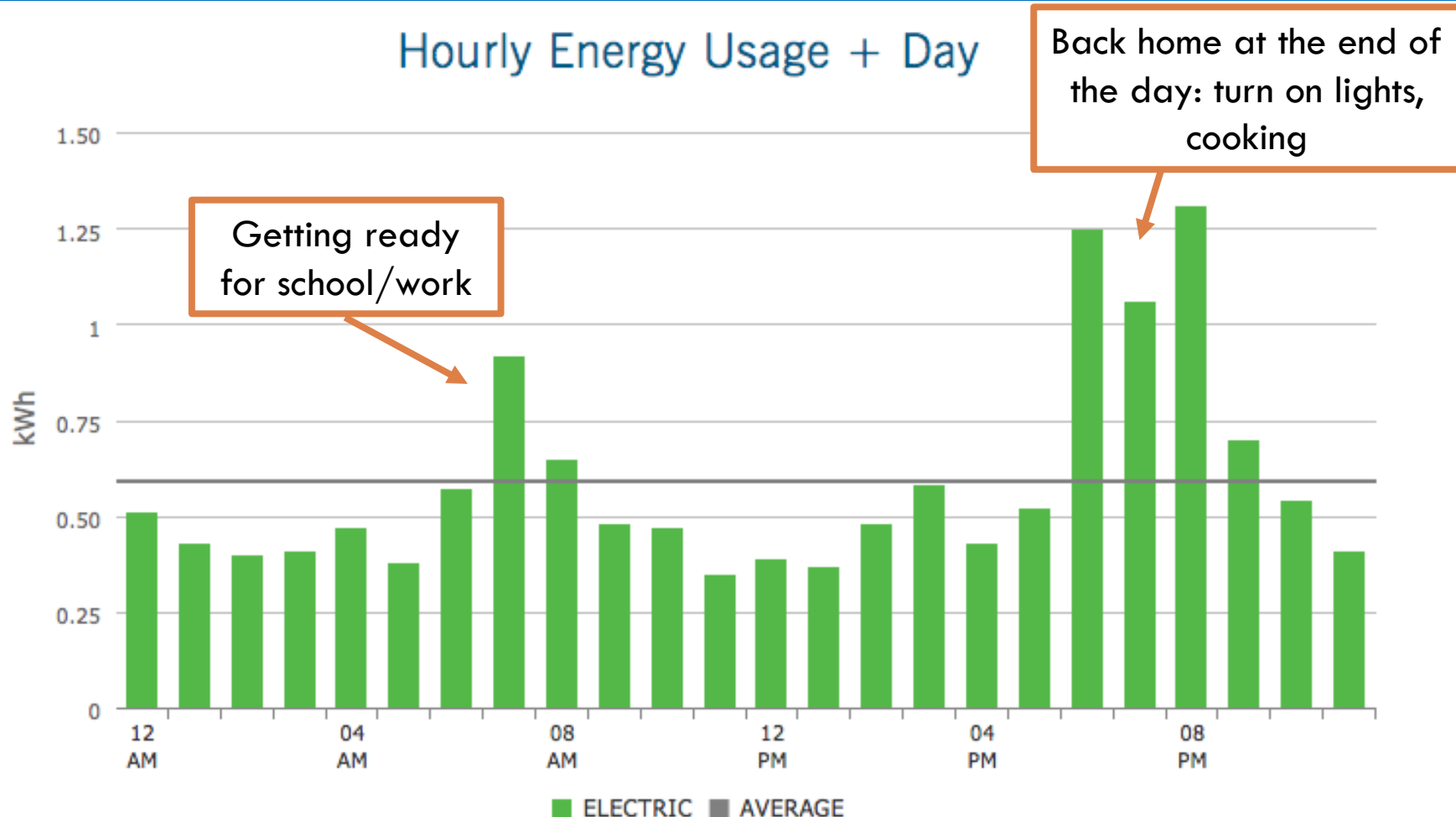
Most appliances can be programmed already, but do we use that feature??
Wouldn't it be nice if they did it automatically?

Information Flow



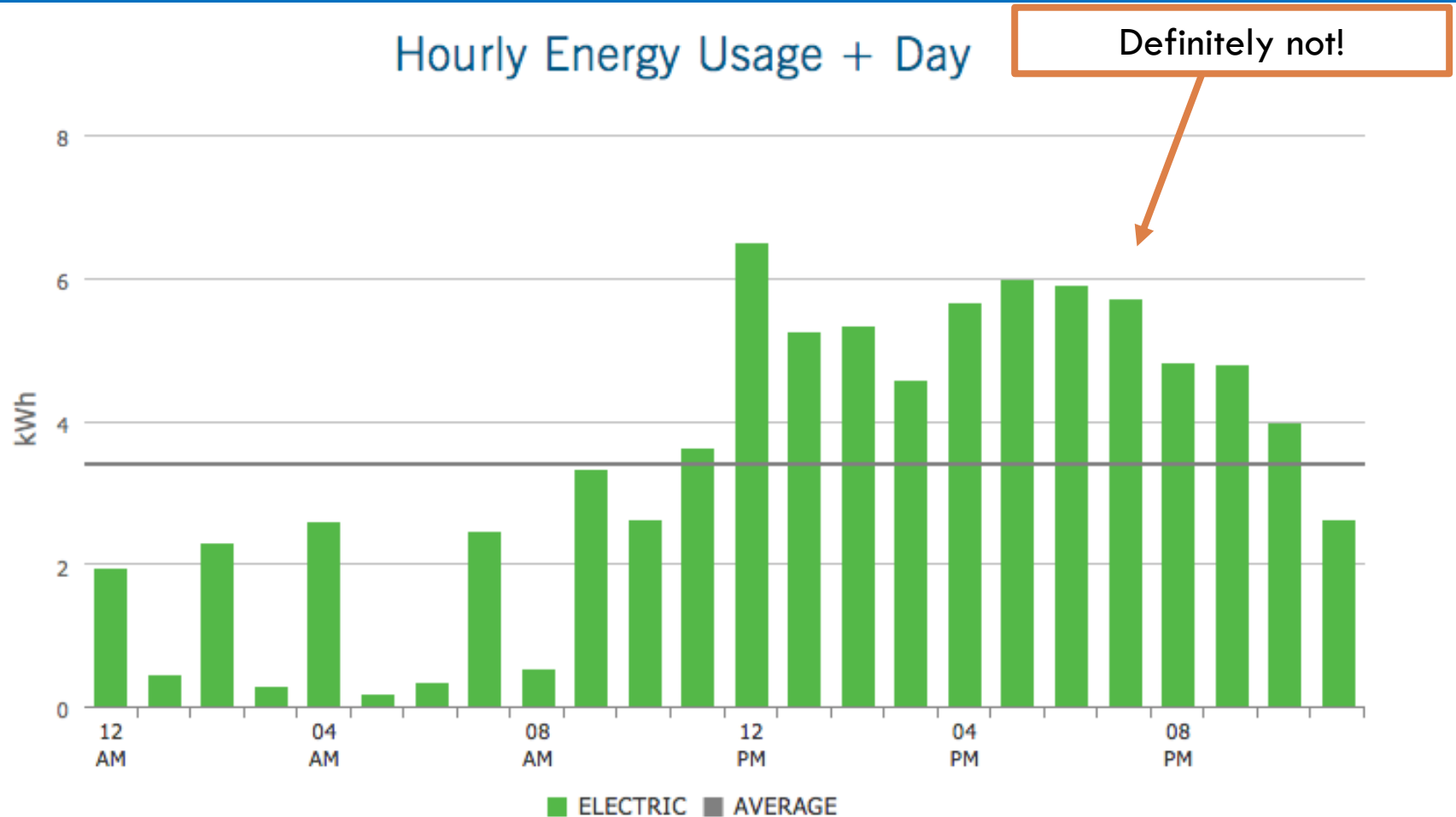
- Information is returned to user via **graph in a mobile app, personal web page, email notification**
 - ▣ User becomes aware of how energy is used and change behavior
- **Information collected** for the user and decisions are made on his behalf **by his automated equipment**
 - ▣ Ex. Nest thermostat
- Flow of information is reversed
 - ▣ **User gathers awareness and make informed decision**
 - ▣ User directly control appliances (remotely)
 - ▣ Ex. Program you dishwasher to run when your solar panels are at peak production

Hourly use for April 25th



This a typical residential demand curve. But is it true year-round?

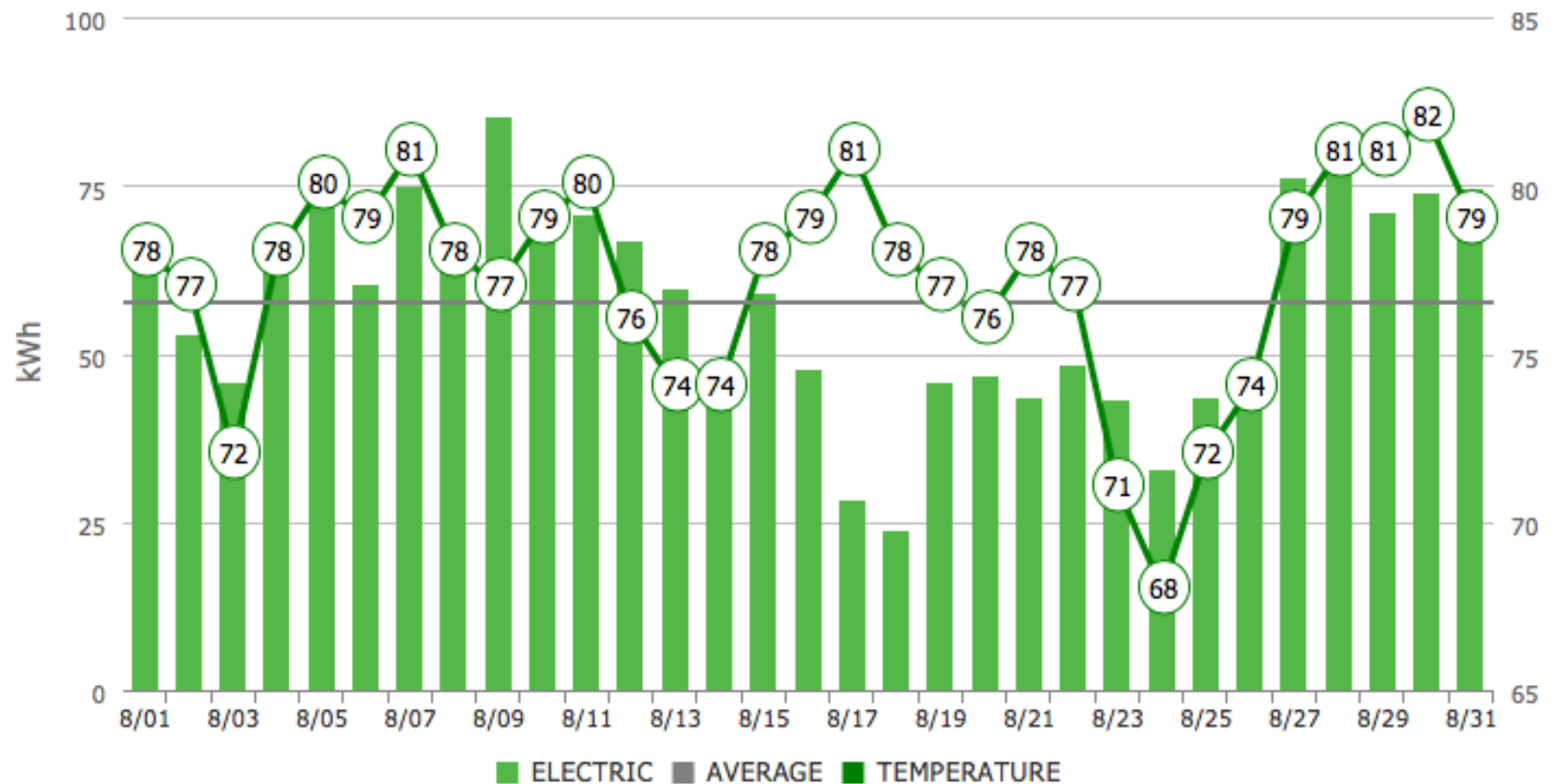
Hourly use for July 27th



What about within a month?

Daily Energy Use: August

Daily Energy and Avg. + Month



Can you see the value of this information?



The Utility/DSO View

DSO perspectives

- Distribution system operator (DSO) responsibilities
 - ▣ Operating the grid, ensuring safety and availability of energy to its customers
 - ▣ Infrastructure and equipment maintenance
 - ▣ Managing interconnections with other systems
- DSO needs a good model of
 - ▣ the energy needs of users over time
 - ▣ maximum peaks to be expected
 - ▣ how should infrastructure evolve to meet future needs geographically and quantitatively

DSO perspectives

- Need **new precise model** of utilization
- Evolution of the grid now is **no more just about growth of population and urban areas**
- Evolution is also related to the new way of using energy

Distributed intermittent
micro-generation

Home-level storage facilities

Electric vehicles

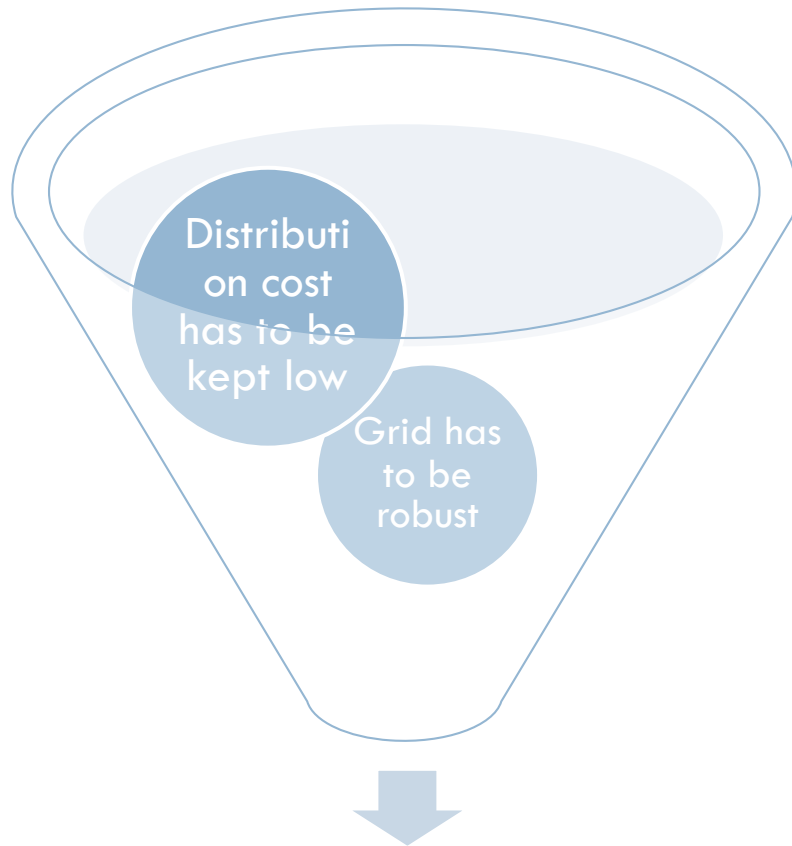


**New players are
changing the game!**

Grid Adaptation

- Distribution grid has been engineered with a radial structure or a tree-like network
- This design is most efficient when there are only few large producer at remote locations
- New paradigm
 - ▣ Energy produced locally
 - ▣ Energy production and consumption take place at neighborhood level
- Designs other than the radial should be investigated

Grid Adaptation



Retrofit Distribution Grid

- Increase in the average connectivity of distribution network that are less close to tree-like structures
- Not realistic to think about rebuilding the distribution grid
- Instead think about how to make current network more efficient without impacting significantly on the cost of infrastructure
- One strategy: upgrade the infrastructure by connecting nodes (not yet connected) that have small distances to each other



More on Smart Meters Adoption

Utility Perspective for AMI

- Potential to save money by reducing congestion in transmission lines
- Limiting the severity of blackouts
- Lowering labor costs associated with meter readers



Consumer Perspective for AMI

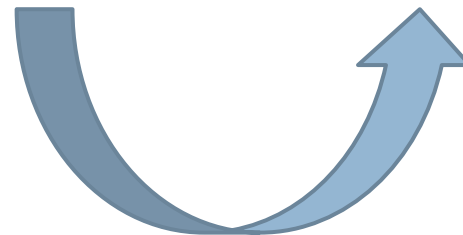
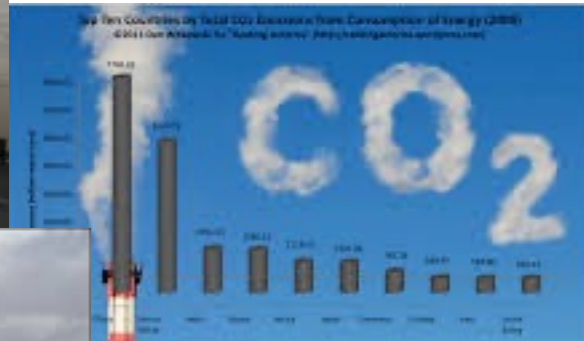
- Real-time pricing information from smart meters to shift electricity consumption away from peak demand to times when it is less costly
 - ▣ Note that most residential electricity rate is flat
 - ▣ But reducing peaks might reduce cost of electricity for the utility (electricity price change throughout the day)
 - ▣ That will further be reflected on your bill when we have rate changes



Environment Perspective for AMI

□ Environmental benefits

They enable utility companies and customers to use electricity more efficiently, thus reducing carbon dioxide emissions



How effectively are AMLs being used?

Vermont Experience

Vermont Study-case (2016)

- 92% of electricity meters in Vermont are now smart meters
- less than 5% of electricity customers have opted out of having a smart meter installed



Survey Conducted - Questions

1. Whether respondents think they **have a smart meter**
2. Whether having a **smart meter has reduced their electricity use**
3. Whether respondents are concerned about any **potential health impacts** due to smart meters
4. Whether respondents are concerned about any **potential impacts on privacy** due to smart meters
5. Whether customers would like to **receive additional information** on smart meters in one or more of the following areas:
 - ▣ how they operate, how they can reduce electricity consumption, power outages, the price of electricity, their impacts on the environment, health, and privacy

Key Findings 1

- ❑ **Only 45%** of survey respondents reported having a smart meter
- ❑ That means that close to half of Vermont's electricity **customers are unaware that they have a smart meter**
- ❑ However, obviously, to maximize the benefits from smart meters, electricity **customers must first be aware that they have them**



Key Findings 2

- Having a smart meter has **not reduced** the electricity consumption of many Vermont residents
 - ▣ only 2.2% reported that having a smart meter significantly reduced their electricity use
 - ▣ 9.6% reported that having a smart meter reduced their electricity use a little bit
 - ▣ **63.7% of respondents reported that the smart meter did not change their electricity use**
 - ▣ 24.5% of respondents were unsure whether the smart meter affected their electricity use

Key Findings 3

- Decrease in electricity consumption is not more widespread because these individuals are not accessing the information that smart meters provide
- Need to ensure information provided by smart meters is easily accessible
 - ▣ in-home displays, the electricity bill, and online tools and apps
 - ▣ will help to promote a greater change in consumers' consumption/behavior

Key Findings

- Rather than decreasing total consumption, smart meters may provide an **incentive to shift the time of day** when electricity is used
- Respondents were two times **more** likely to report being **concerned** about the potential impact of smart meters on their **privacy than health**
- The highest percentage of respondents (30.8%) **wanted information** on how smart meters work
- The lowest percentage of respondents (23.8%) wanted **information on smart meters' potential impact on privacy**

Key Findings

- No more than 30.8% wanted any kind of information on smart meters
 - ▣ Lack of interest in or knowledge of smart meters
- Need to increase education on smart meters and the benefits they can provide
 - ▣ Unbiased disseminator of information, i.e., a trustworthy source

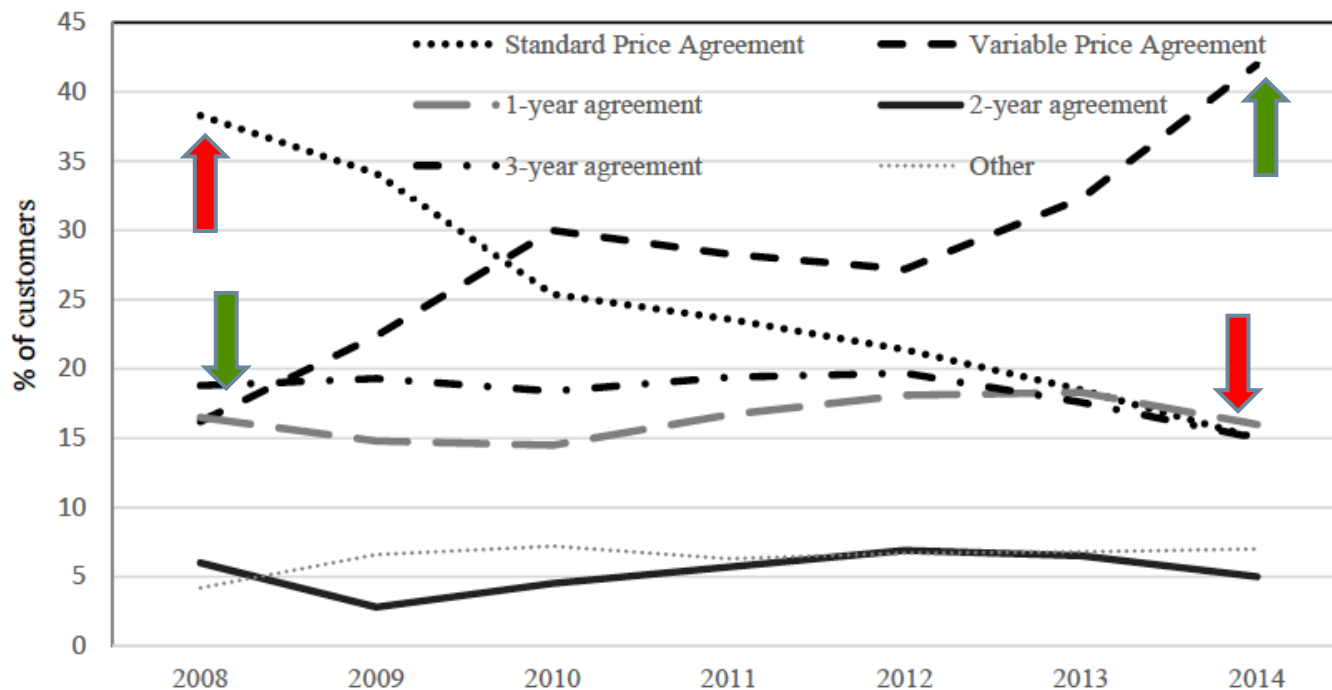
Takeaway: Smart meters are not being used smartly

How effectively are AMLs being used?

Sweden Experience as of 2015

Sweden Experience

- One of the first countries to install smart meter for all customers
- Significant transition in the amount of customers shifting from default (fixed-price) contracts to variable-price contracts

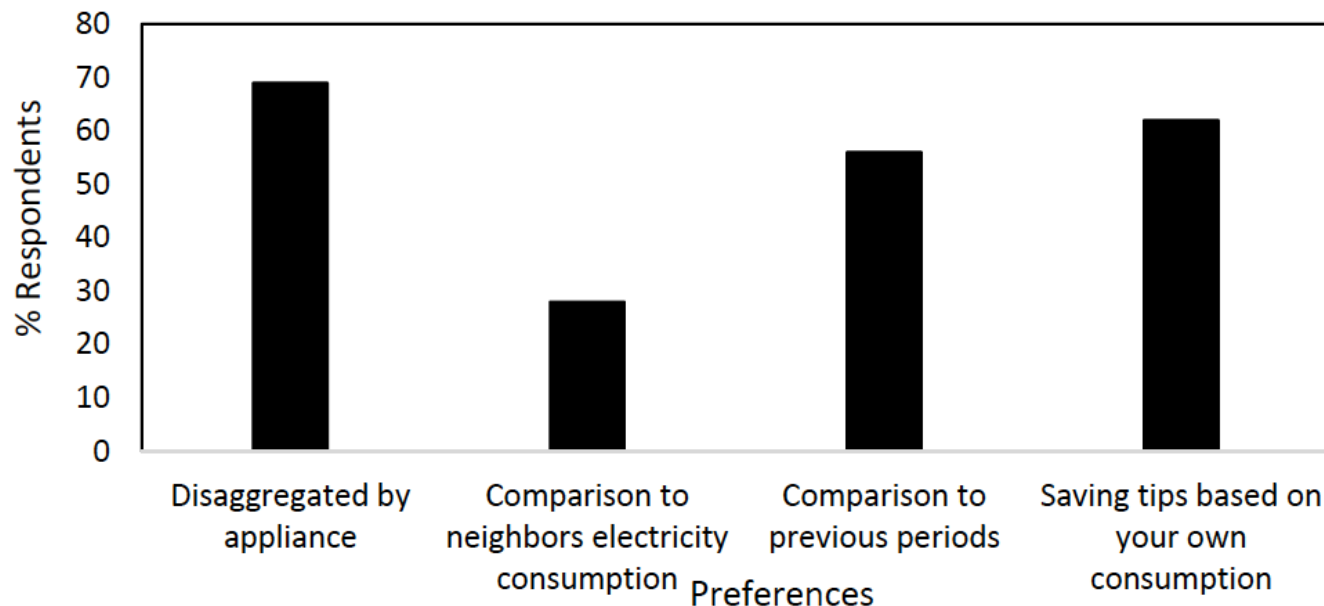


Sweden Experience

- The variable option is still not a time-of-use tariff
- Change of consumer behavior should be linked to options for energy storage, appliances control, security and remote monitoring
- For most consumers electricity is “invisible” and a “product” not actively consumed
- Need to increase “visibility” through feedback

Survey Key Findings 1

- Participants were asked what type of additional information should be included in their electricity bills to help them reduce their consumption



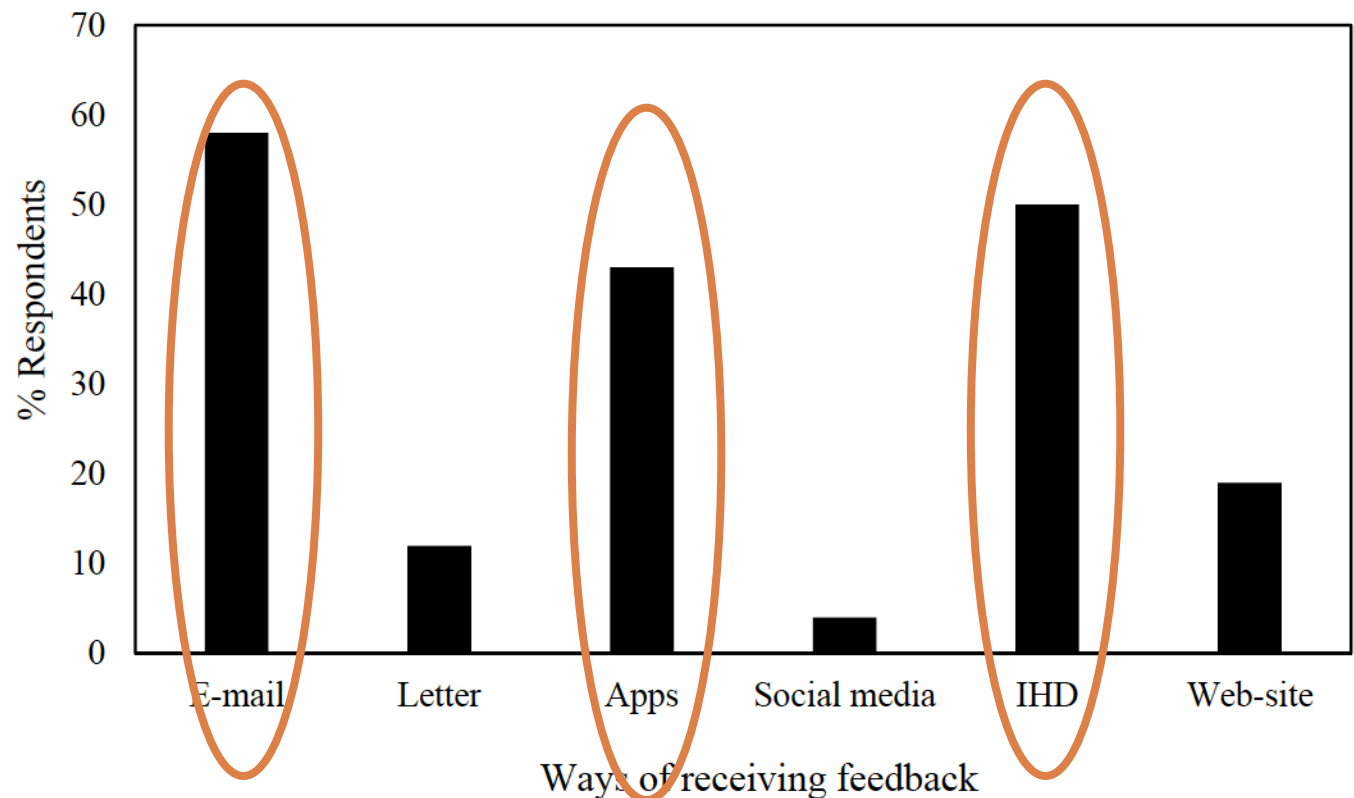
Survey Key Findings 2

- Participants were asked what frequency and how they wanted to receive information about their consumption

57% chose “once per month” as desired frequency

The 26-35 years group actually chose apps as preferred method

The 36-45 years group actually chose IHD as preferred method



Survey Key Findings 3

- Adoption of **real-time pricing and time-of-use** is still **very low**
- Potential of providing customers with more detailed information about energy consumption and access to dynamic pricing has not been exploited by DSOs
- The methods of providing information from smart meters currently used by most DSOs which are **paper bills and web-sites** turn out to be the **least preferred** by the participants

Takeaway: Smart meters are not being used smartly!



Group Discussion

Topics for discussion

- How much the advent and success of Smart Grids depend on the full roll out of Smart Meters?
- Knowing how the internet developed and changes our daily lives, can we draw a parallel with Smart Grids and predict their evolution in the future?
- How to educate consumers on how to use smart grid?



THANK YOU !

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