ETH zürich

Smart Energy

Electricity usage and demand side management in households

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Ubiquitous Computing Seminar FS2014

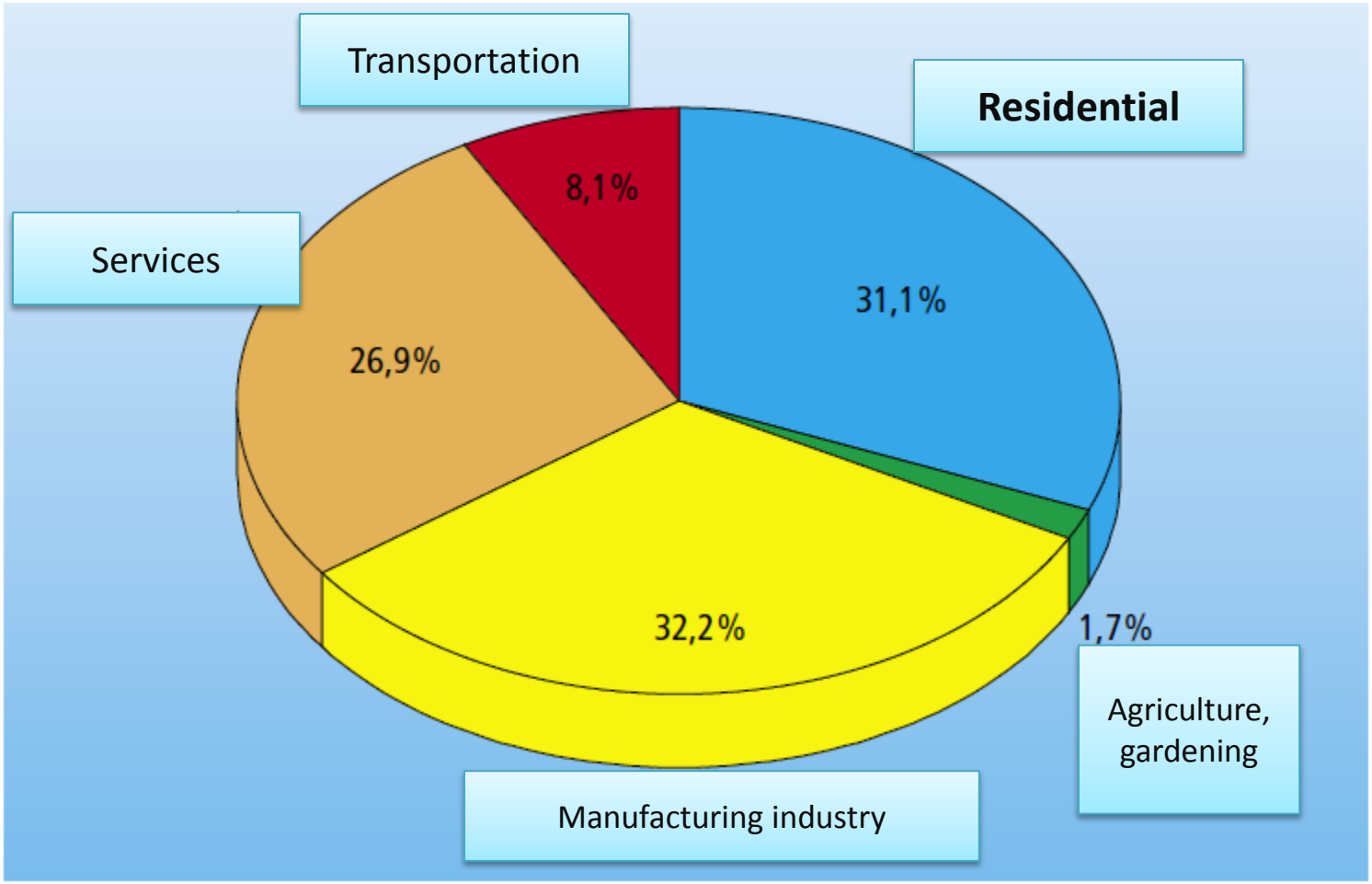
Topics

Problems	Peak Load	Reduction in consumption
Approach	Demand Side Management (DSM)	Improved feedback
Tools	Dynamic Pricing, Load Control	Appliance level data
Technologies	Ripple Control Smart Thermostat **SmartMeters** Energy monitors In-Home displays	

0. Energy statistics and overview of the grid

Energy Statistics

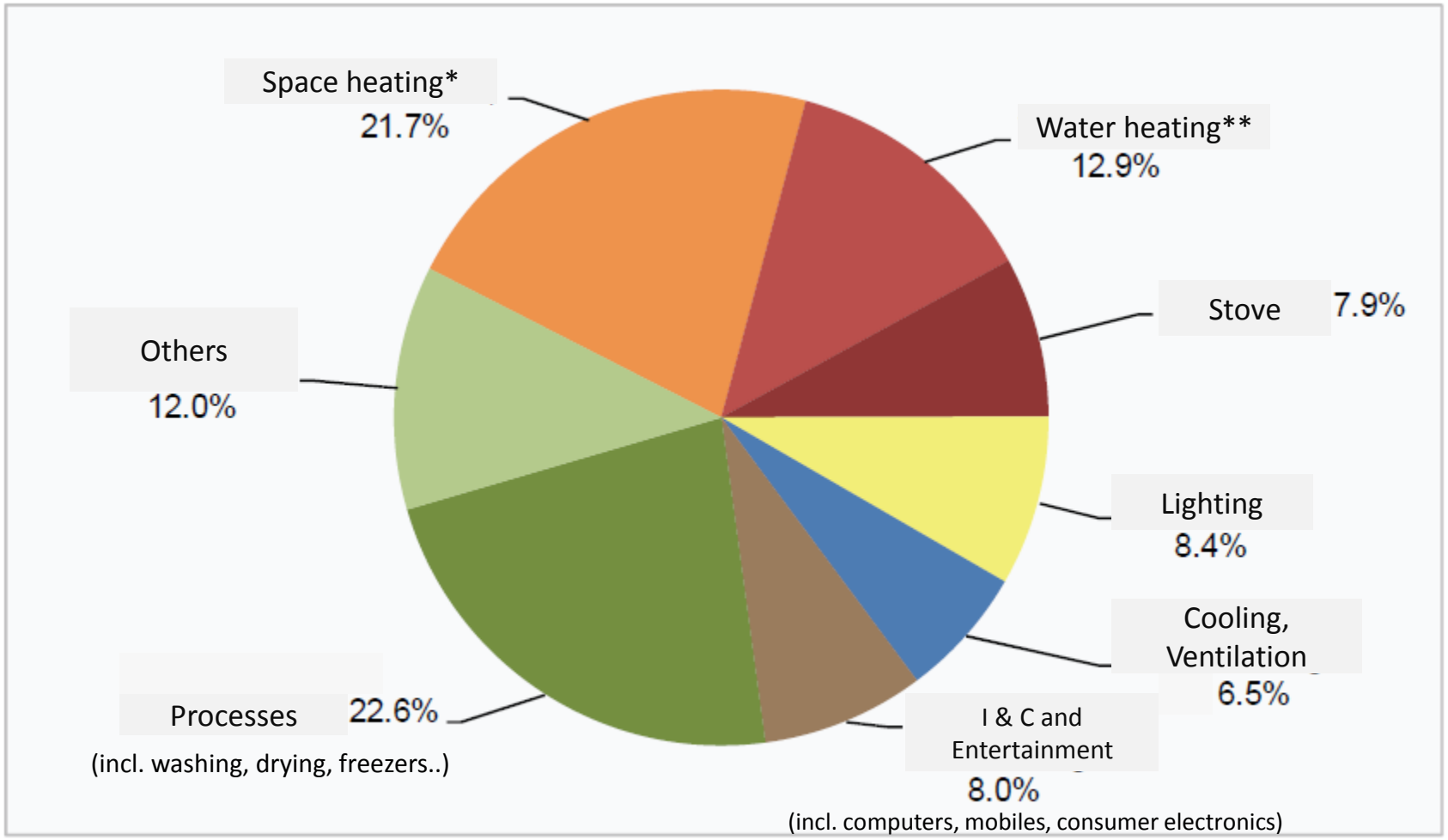
Electrical Energy usage in Switzerland according to **sector**



Source : Schweizerische Elektrizitätsstatistik 2012, BFE

Energy Statistics

Electrical Energy usage in Switzerland in **residential sector**

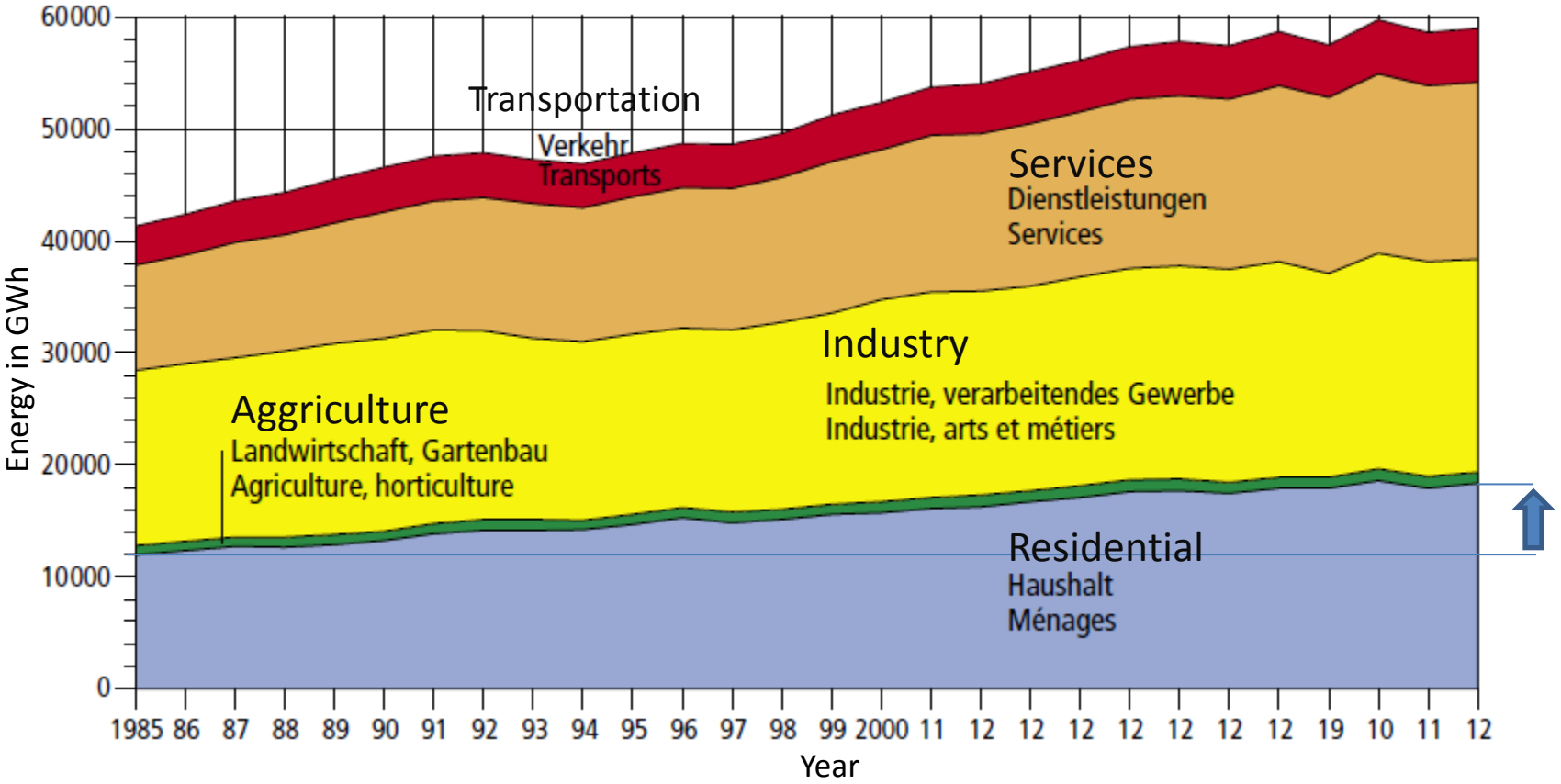


* Electricity only accounts for 8% of total energy used for space heating - rest comes from fossil fuels.
** Electricity accounts for 25% of total energy used for water heating.

Source : Schweizerische Elektrizitätsstatistik 2012, BFE

Energy Statistics

Change in Electrical Energy usage in Switzerland over the last two decades



Residential sector has shown a significant rise in consumption – part of this has been attributed to population growth and partly to increase in per-head consumption.

Source : Schweizerische Elektrizitätsstatistik 2012, BFE

The Heterogeneous Grid

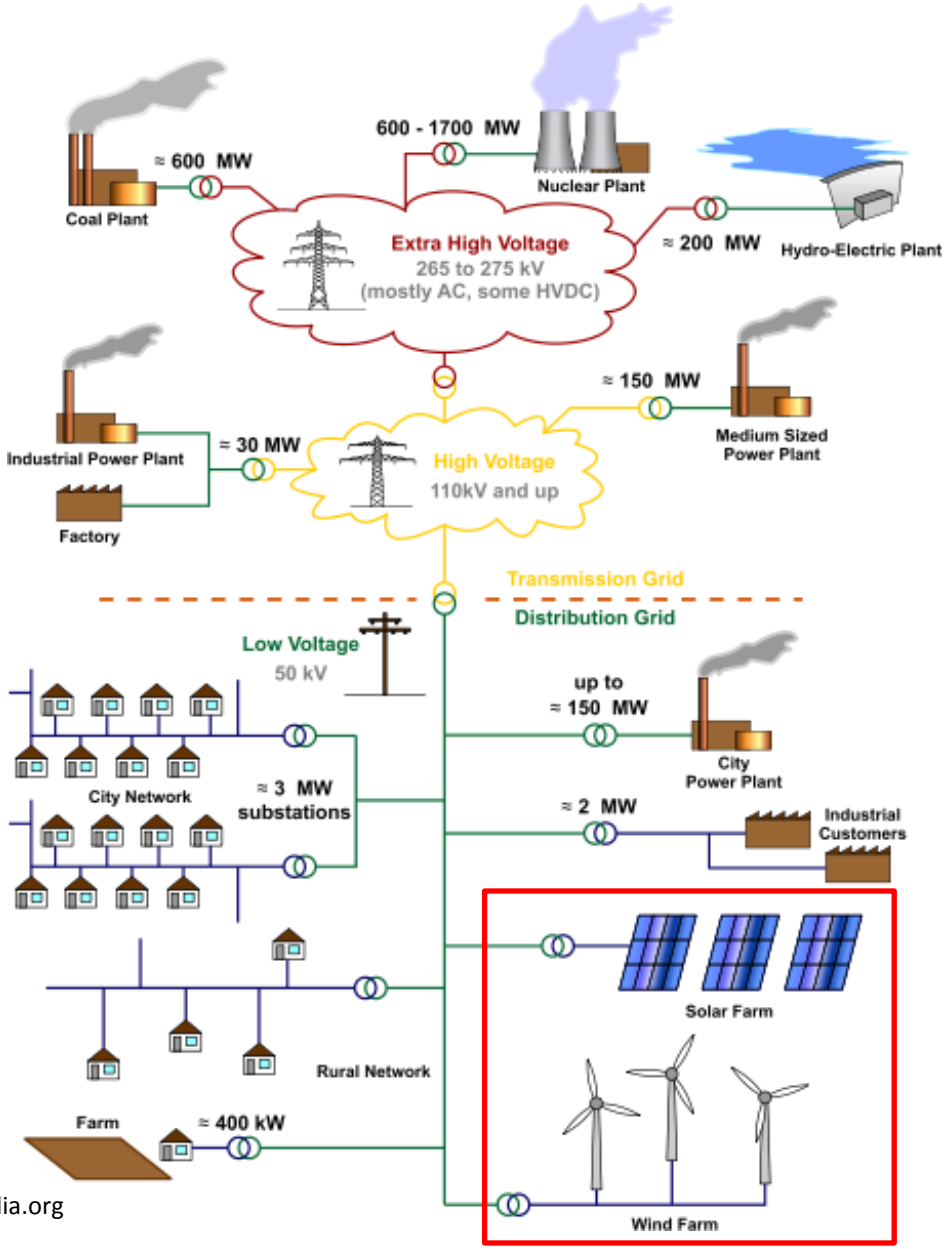
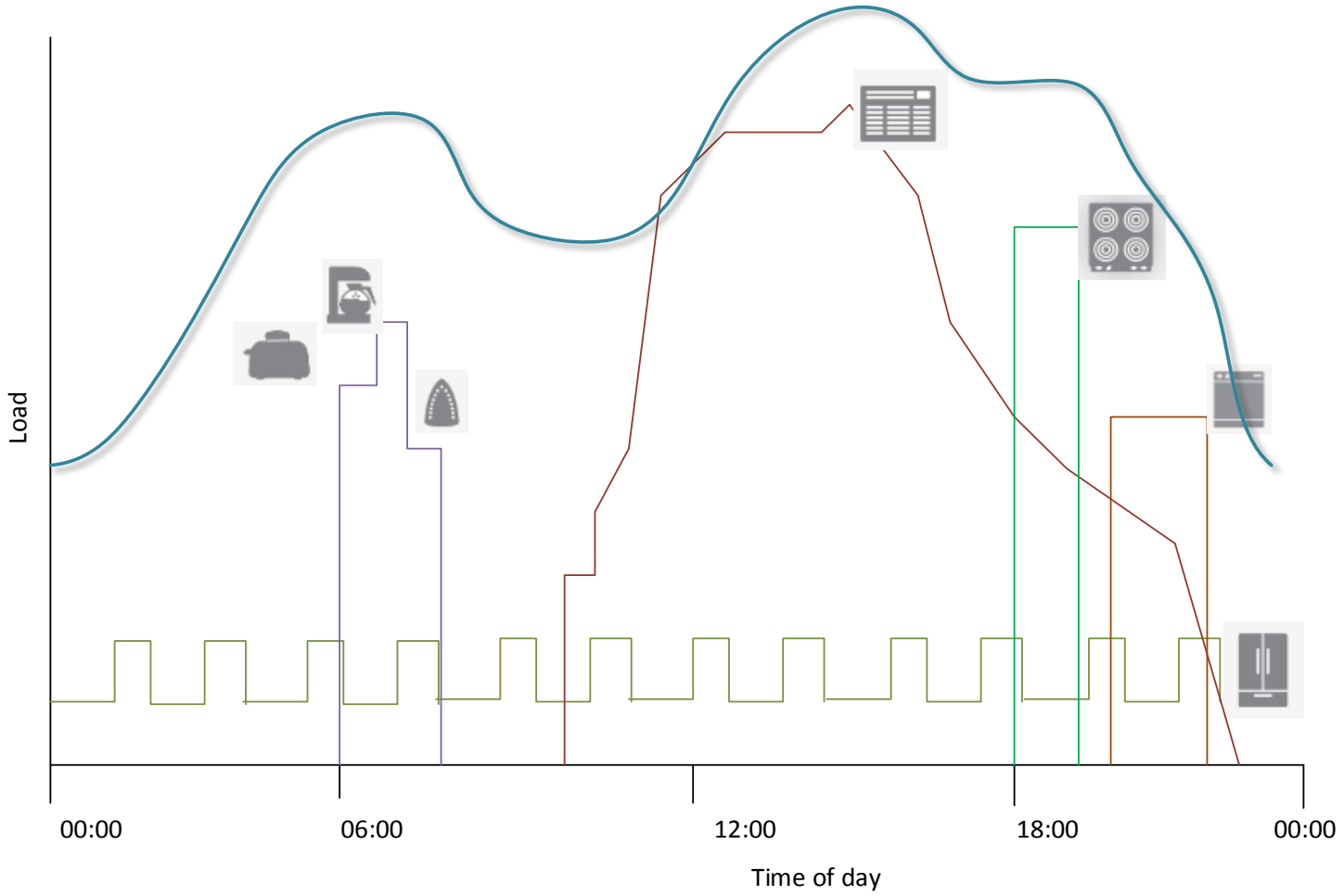


Image source : www.Wikipedia.org

1. Peak Load

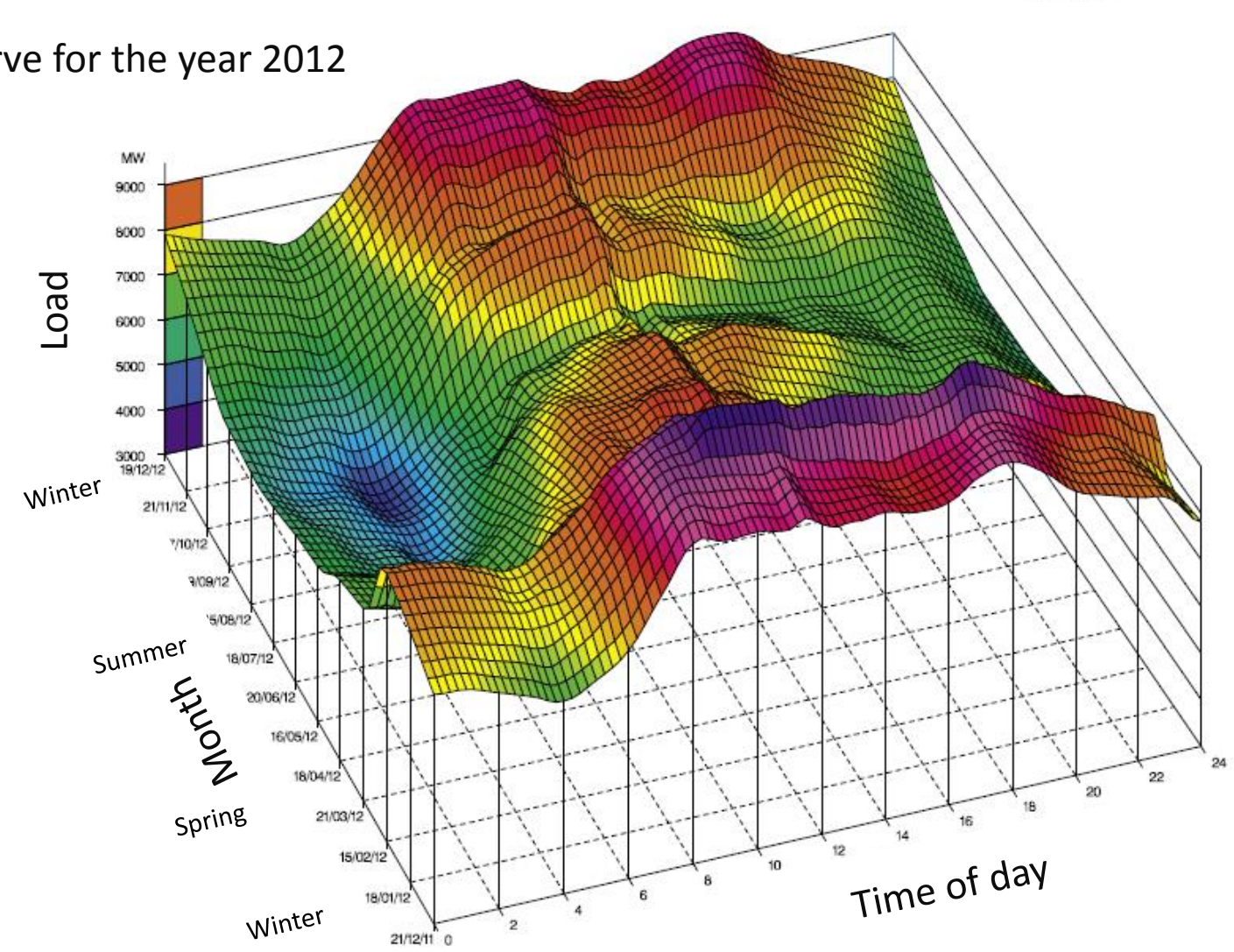
The Load Curve



The load curve as seen by the electricity supplier is a result of stochastic processes!

Peak Load

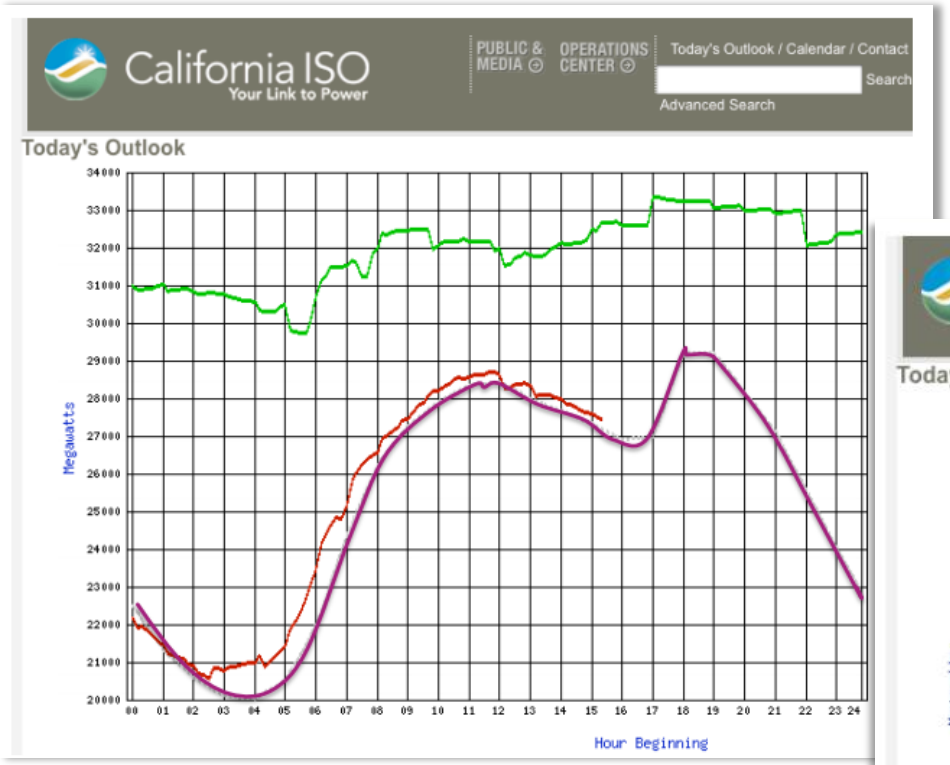
Load curve for the year 2012



Source : Schweizerische Elektrizitätsstatistik 2012, BFE

Peak Load

Dangerous peak!



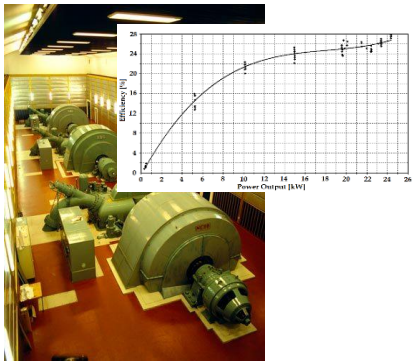
Resource Forecast
Demand Forecast
Actual Usage

Source: Mathieu, ETH Zürich «Demand Response Today» CDC Workshop 2013

Catering for Peak Load

Generation capacity needs to be sized for peak-load. This results in redundant capacity (nearly 50% in the U.K., for example)

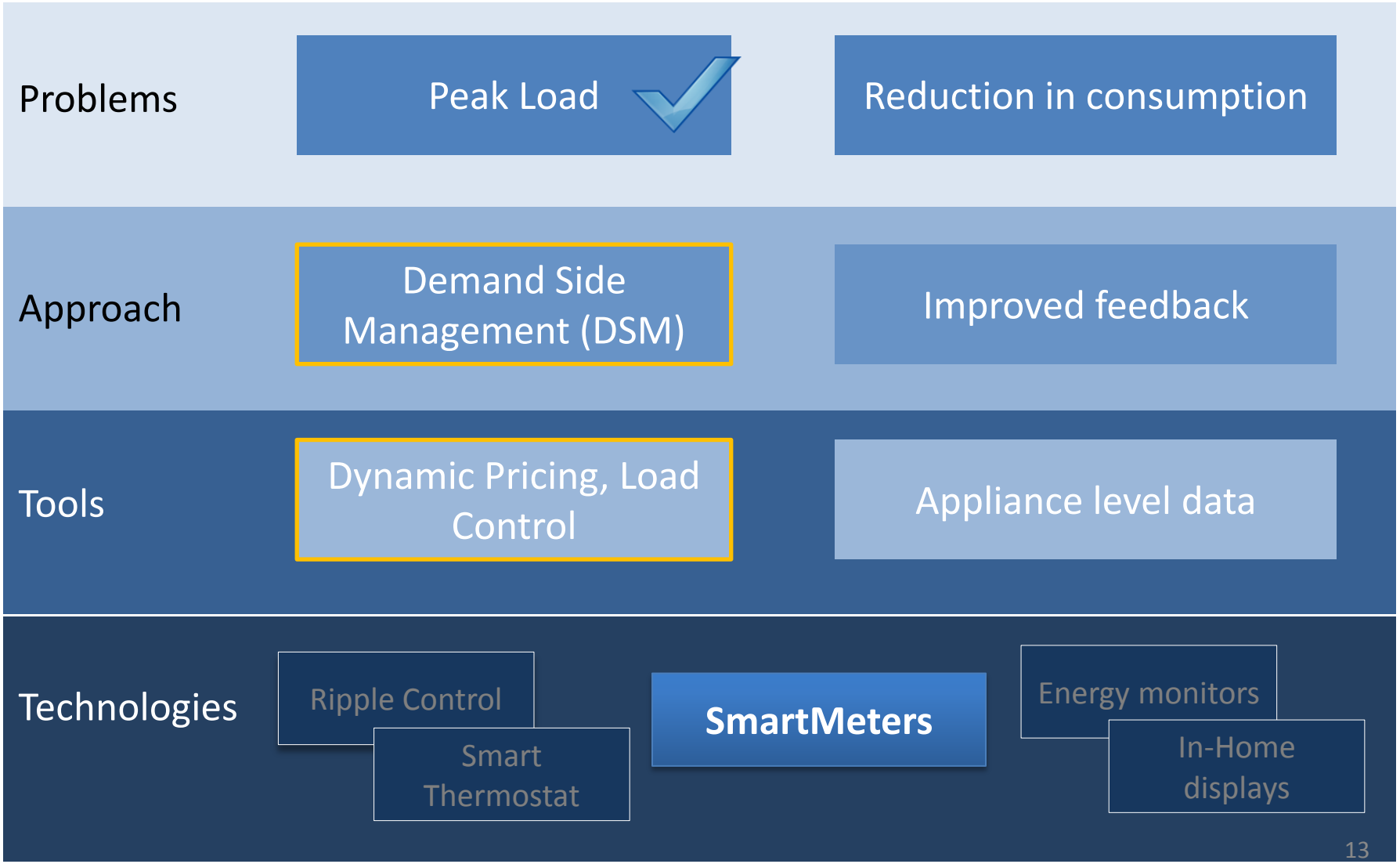
Distribution grid needs to be sized for peak-load. Also, makes energy economics sub-optimal.



Below optimum operation of the generator due to part capacity.

Image source : www.Wikipedia.org

Where are we?


Problems
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Reduction in consumption
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Improved feedback
Tools
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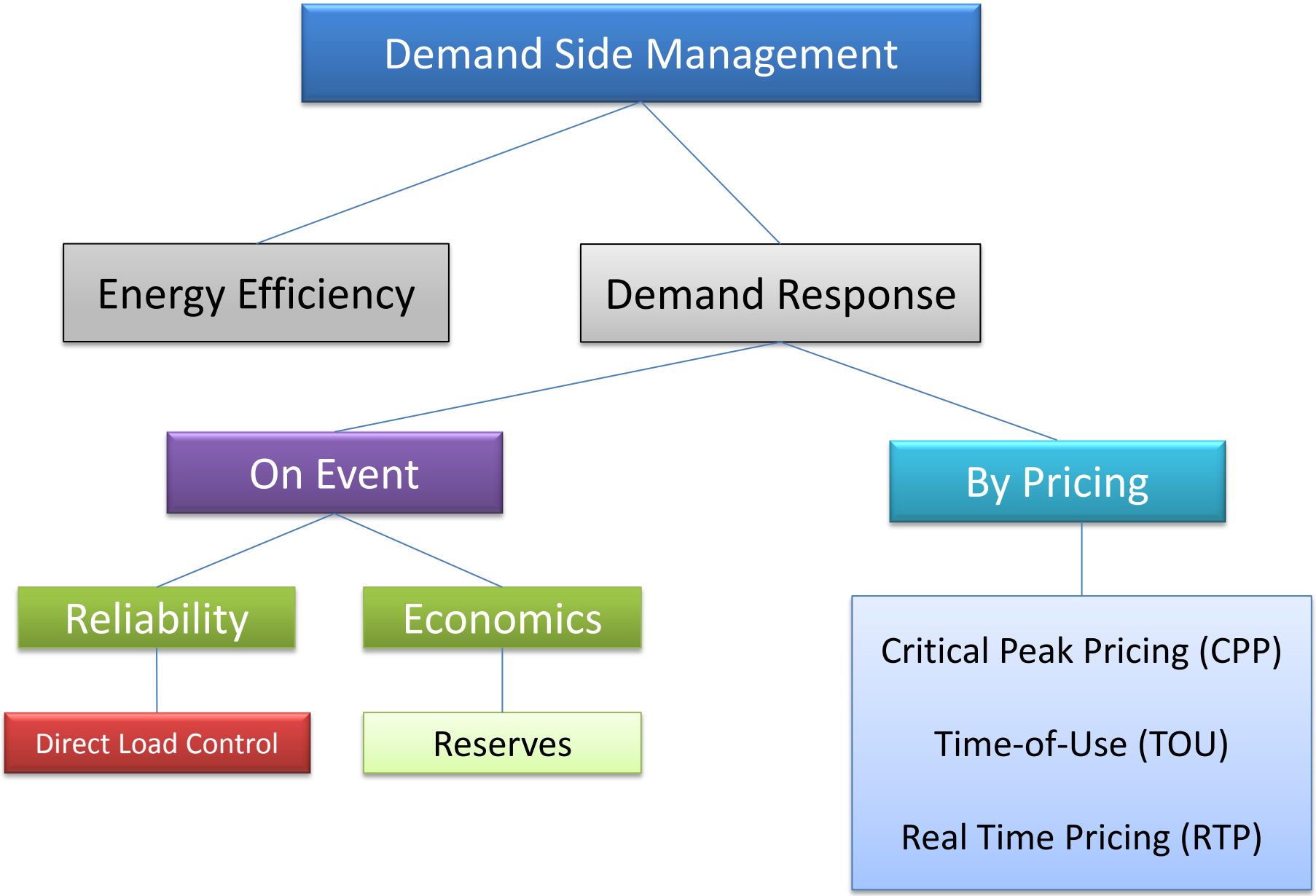
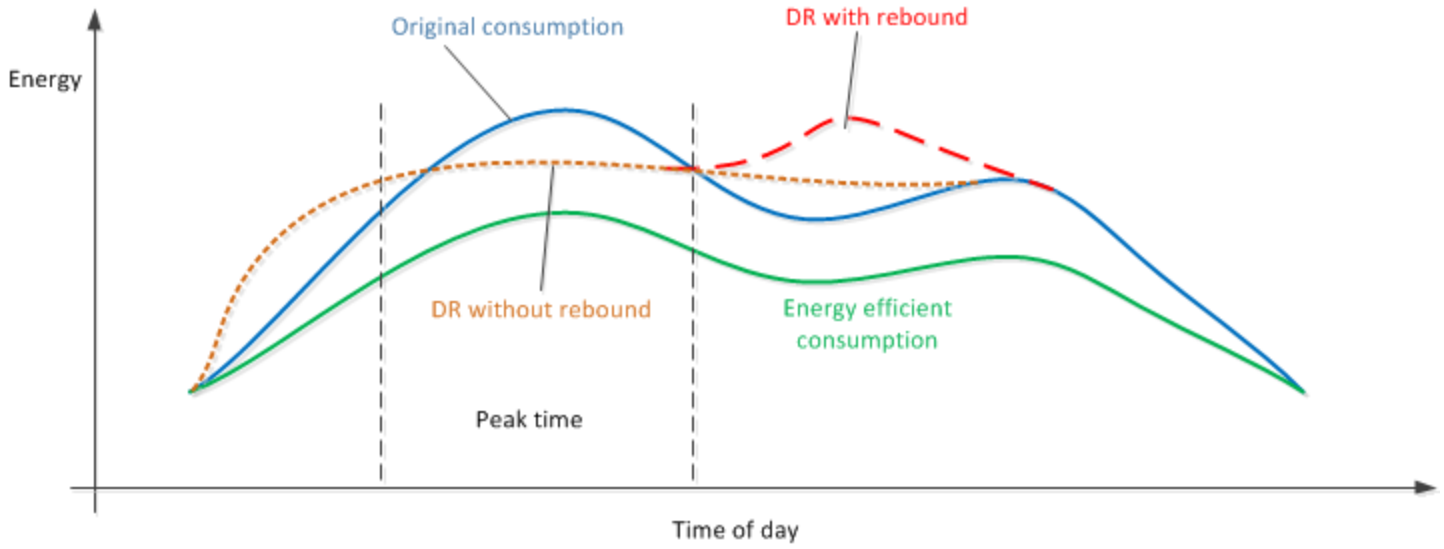
Smart Thermostat
SmartMeters
Energy monitors
In-Home displays

2. Demand-Side Management



Adapted from "Demand Response Measurement & Verification", AEIC, 2009

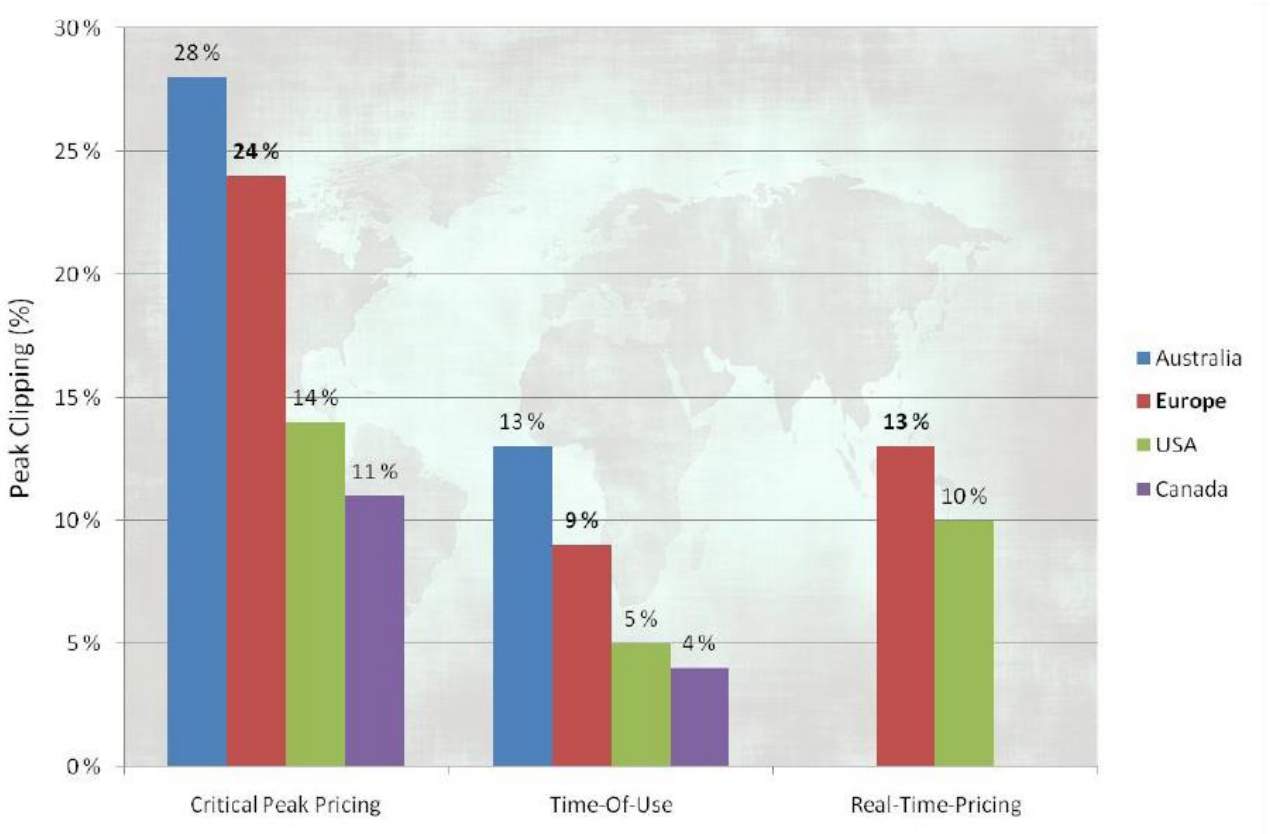
Demand Response



Adapted from “Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads”, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 7, NO. 3, AUGUST 2011

Price Based Demand Response

Effect of dynamic pricing on residential consumption



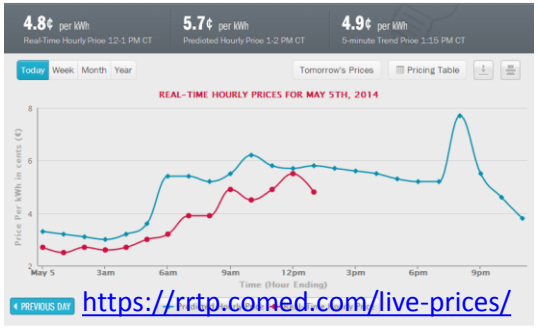
Example: In Kanton Zug – Off-peak tariff = 10 Rp /kWh, Peak = 21 Rp / kWh

Source: Strombeck et. Al "The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison", ESMIG, 2011

Automation to support Dynamic Pricing

Many newer household equipments like dishwasher or air-conditioners have the ability to program timed operations.

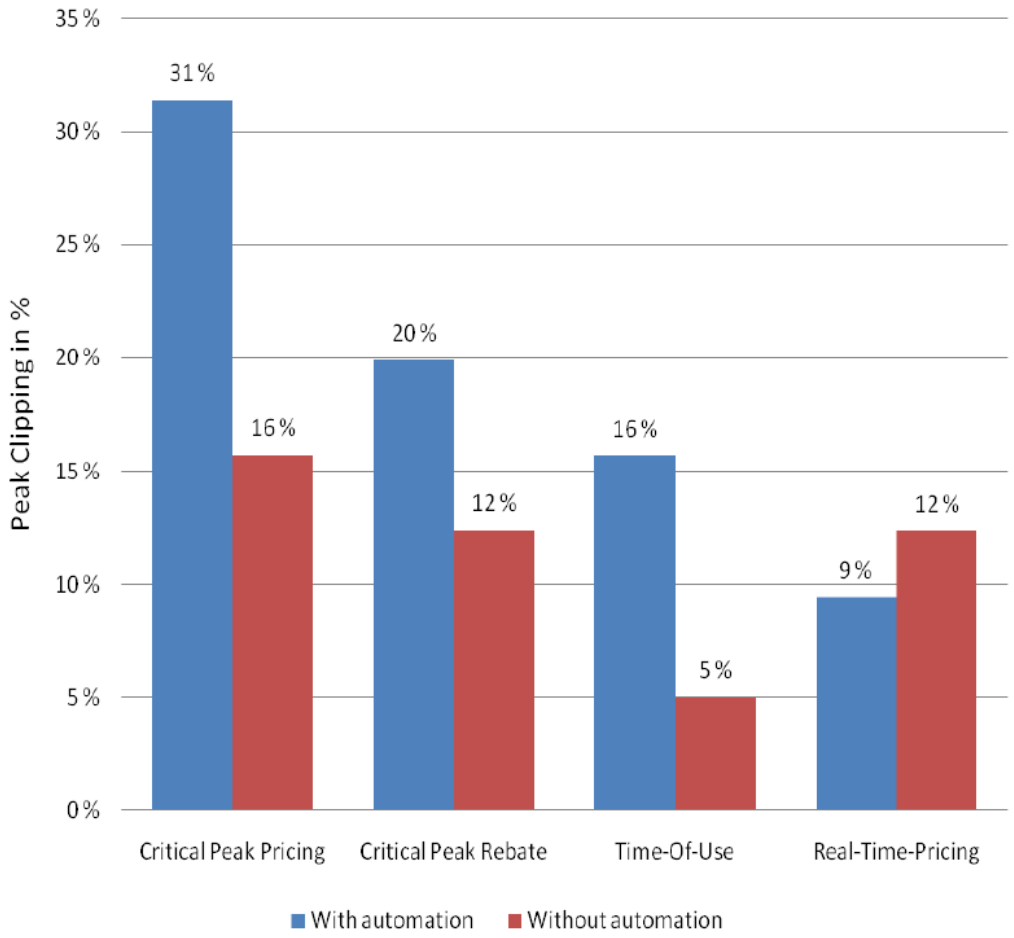
High end solutions use a logic controller to schedule the operation of pumps, heaters etc. based on pricing signals.



Real-time pricing is not so common in household. Some utilities have started offering it along with switching controllers for air-conditioning and e-car chargers.

Image sources: www.orangedove.com www.v-zug.ch www.janitza.com, www.rrtp.comed.com/live-prices/

Effect of automation on peak clipping



Source: Strombeck et. Al "The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison", ESMIG, 2011

Direct Load Control

Source: Landis & Gyr, Switzerland

Ripple control (Rundsteuerung)

Overlays audio frequency signal on supply

Example : EWZ (Zürich) uses 375 and 1600 Hz with "*Decabit*" encoding
(detailed information in www.rundsteuerung.de)

+ Simple, proven technology
- No feedback
- Limited granularity of control
- Limited data content

Image Source: www.wikipedia.org

Direct appliance control

Limited to using ripple control, proprietary radio signals

- Very limited technology options!

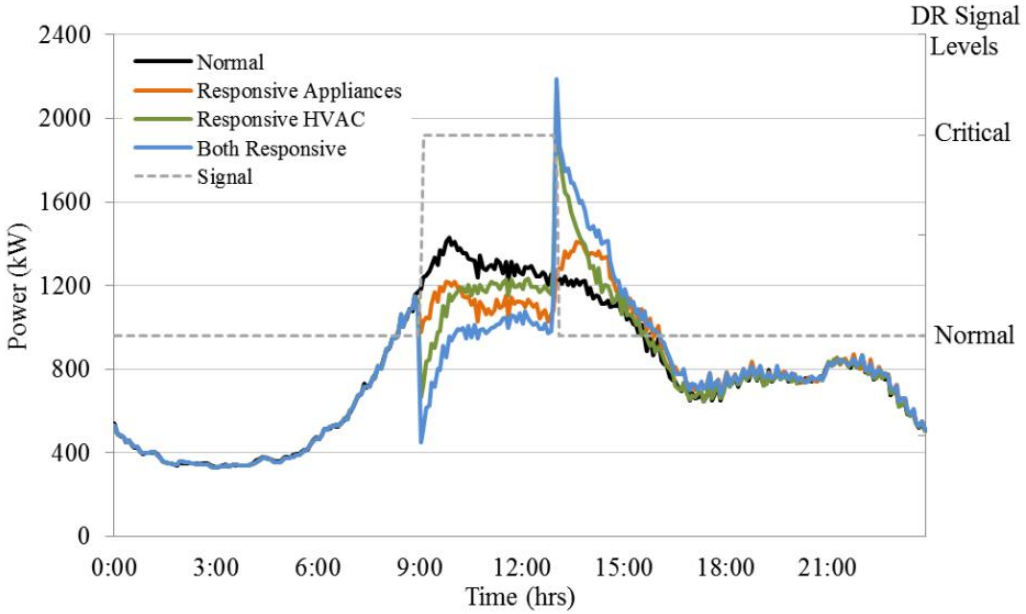
Image Source: www.ecobee.com

SmartThermostat

Based on openADR specification (ecobee, Honeywell) for implementation in California.

+ Strong data exchange schema
- Not a widely known or accepted standard

Rebounds can be terrible!

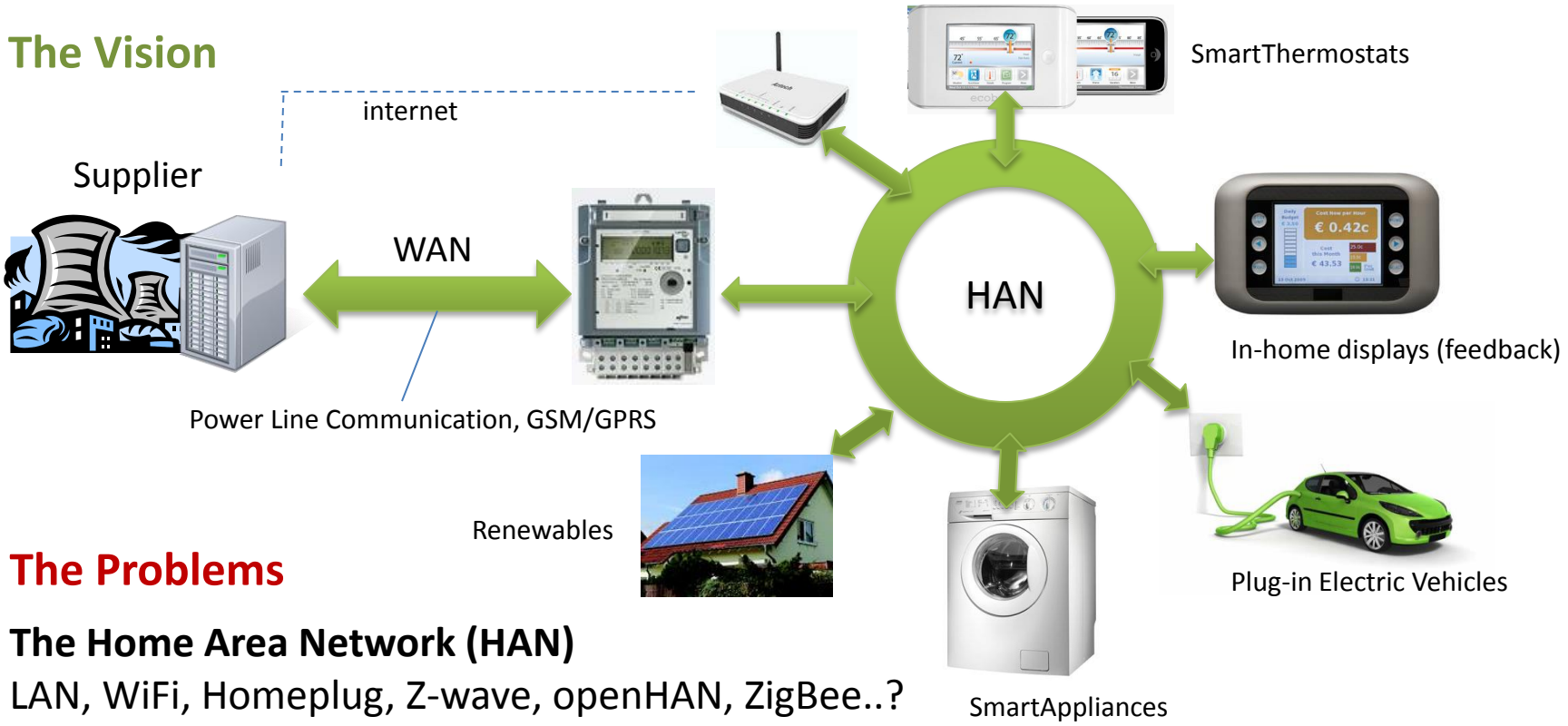


Automated Demand Response needs to be *Smart*!
(Adaptive, collaborative, intelligent appliance level algorithms..)

From: Fuller et al "Modeling of GE Appliances in GridLAB-D:Peak Demand Reduction", U.S Department of Energy, 2012

Technology support for DSM

The Vision



The Problems

The Home Area Network (HAN)

LAN, WiFi, Homeplug, Z-wave, openHAN, ZigBee..?

Application protocol

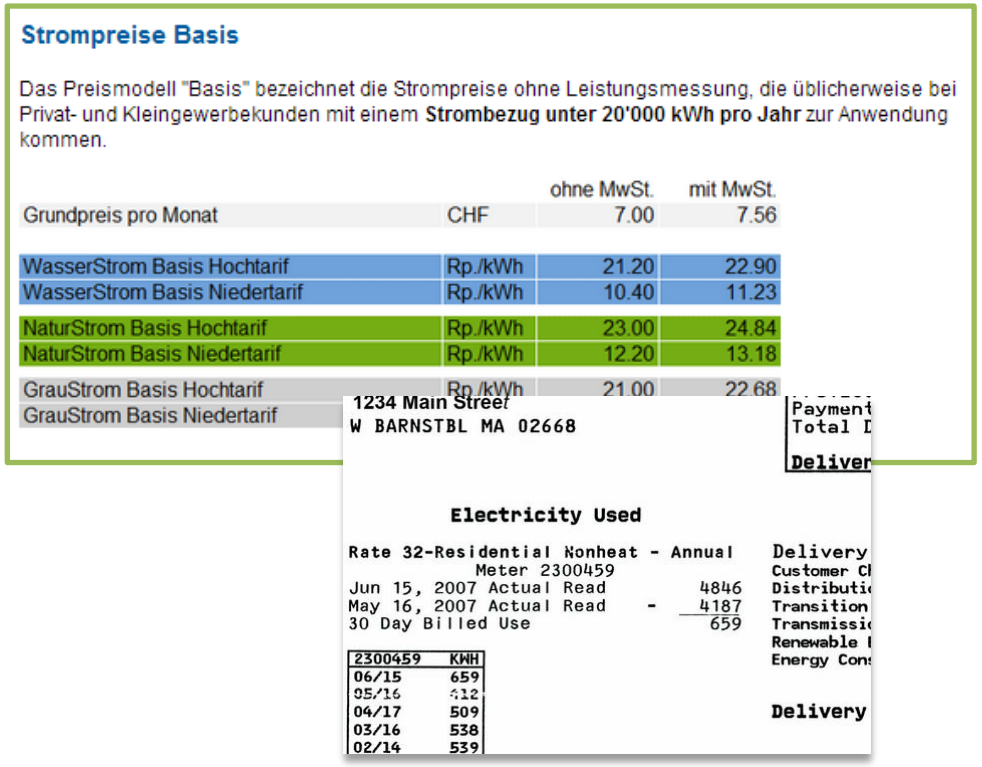
openADR, ZigBee SEP, ...?

Application protocols need to model user needs and behaviour (like need for override)

Challenges to Demand Side Management

*The role of DR in the international electricity arena remains rather small, with 2008 peak load reductions reaching an average of just 2.9% in European countries and around 5% in the U.S.**

1. **Awareness – lack of feedback**
2. Lack of usage data
3. Response Fatigue
4. Low potential savings
5. Implemenation cost
6. Lack of standards and interoperability
7. Behavioural issues



Strompreise Basis

Das Preismodell "Basis" bezeichnet die Strompreise ohne Leistungsmessung, die üblicherweise bei Privat- und Kleingewerbekunden mit einem **Strombezug unter 20'000 kWh pro Jahr** zur Anwendung kommen.

		ohne MwSt.	mit MwSt.
Grundpreis pro Monat	CHF	7.00	7.56
WasserStrom Basis Hochtarif	Rp./kWh	21.20	22.90
WasserStrom Basis Niedertarif	Rp./kWh	10.40	11.23
NaturStrom Basis Hochtarif	Rp./kWh	23.00	24.84
NaturStrom Basis Niedertarif	Rp./kWh	12.20	13.18
GrauStrom Basis Hochtarif	Rp./kWh	21.00	22.68
GrauStrom Basis Niedertarif			

1234 Main Street
W BARNSTBL MA 02668

Payment
Total D

Deliver

Electricity Used

Rate 32-Residential Nonheat - Annual
Meter 2300459

Jun 15, 2007 Actual Read		4846
May 16, 2007 Actual Read	-	4187
30 Day Billed Use		659

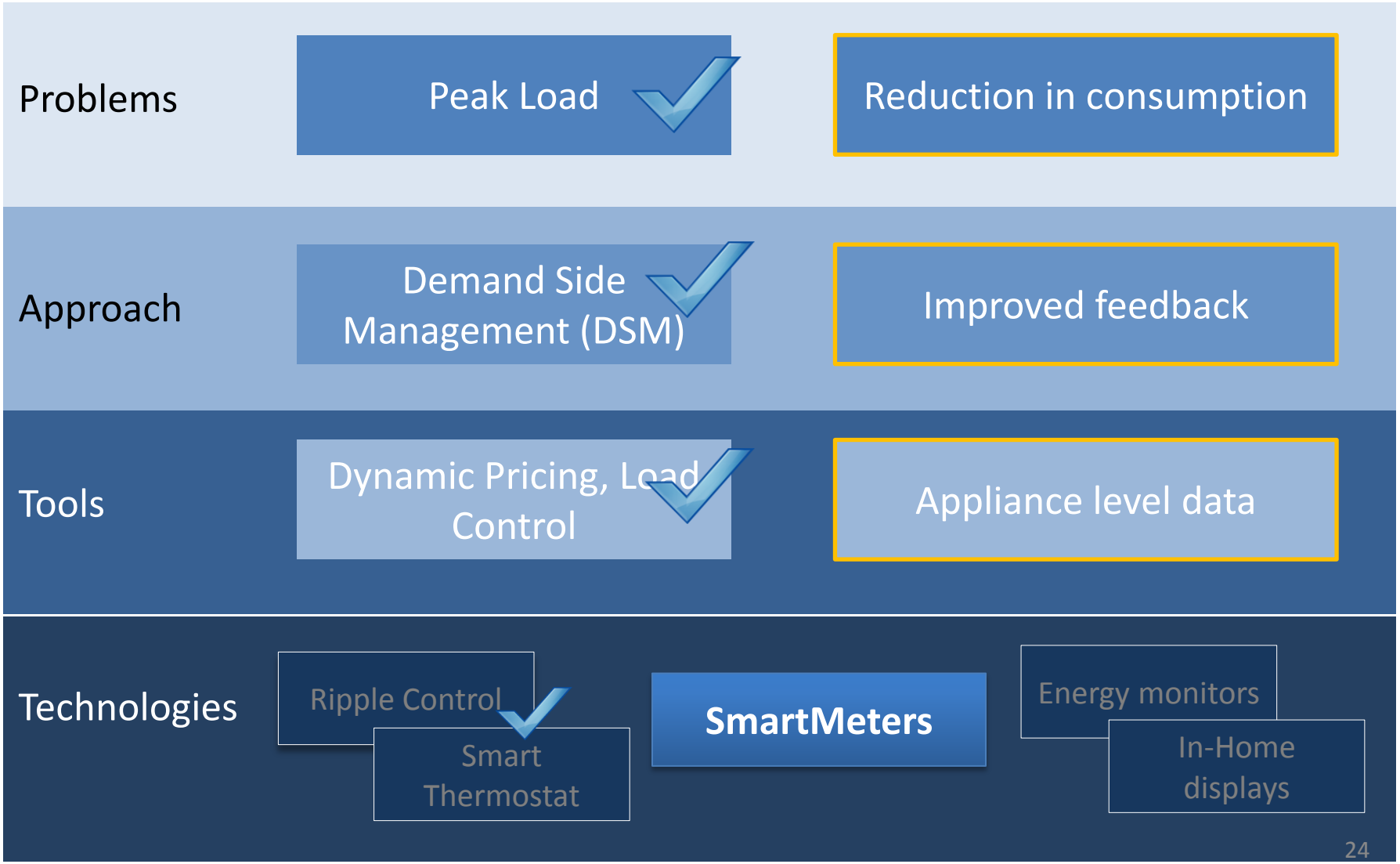
Delivery
Customer Cl
Distributi
Transition
Transmissi
Renewable
Energy Cons

2300459	KWH
06/15	659
05/16	412
04/17	509
03/16	538
02/14	539

Delivery

*Kim, Scherbakova “Common failures of demand response” Energy, 2010 Elsevier

Where are we?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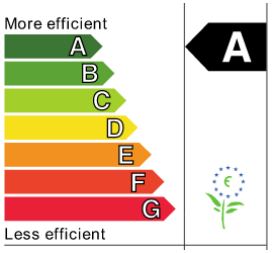
3. Achieving energy savings in homes

How do we achieve energy savings in households?



1. Use energy efficient appliances, curtail usage.

2. **Provide feedback so that the user adopts energy-efficient behaviour**

Energy usage feedback

Too less, too much, too late, too simple, too complex, irrelevant, abstract..
..and rarely right!

Key findings about feedback

Effective when it is..

- provided frequently, as soon after the consumption behaviour as possible.

(example: what if you oven told you how much energy was used in baking)

- customized to the household's specific circumstances.

(example: south facing apartment?)

- provided relative to a meaningful standard of comparison.

(example: compare a family household with the like)

- **with appliance-specific consumption breakdown (some studies).**

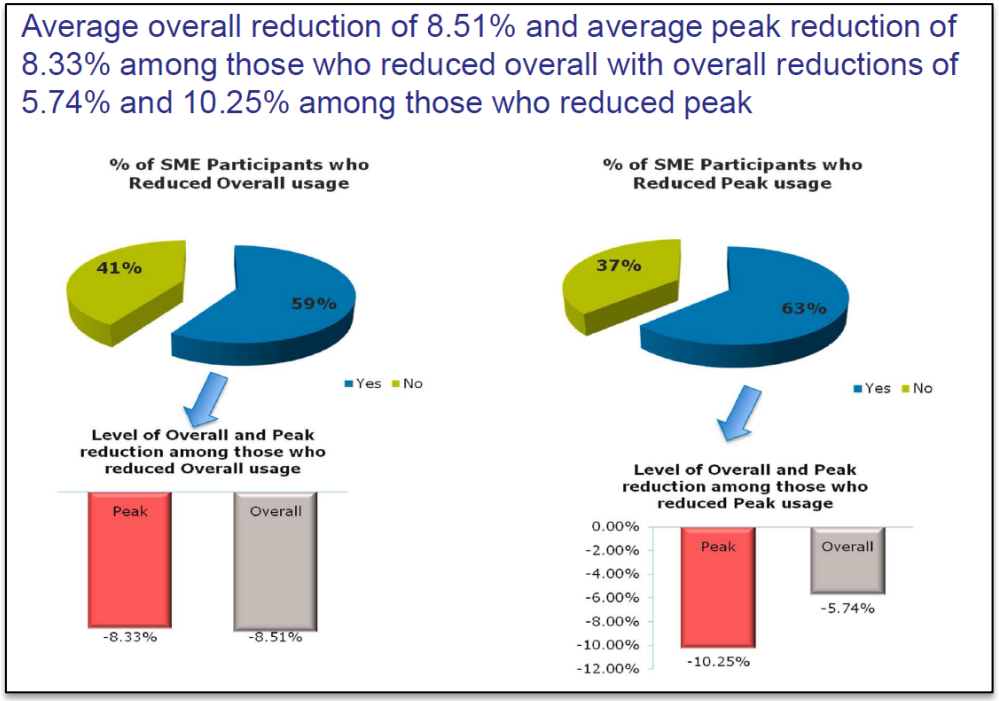
From: Armel et al, "Is disaggregation the holy grail of energy efficiency? The case of electricity", Energy Policy, 52, 2013.
Neenan, "Residential Electricity Use Feedback: A Research Synthesis and Economic Framework", EPRI, 2009
Wess et al, "Evaluating Mobile Phones as Energy Consumption Feedback Devices", Mobiquitous, 2010

Energy savings – mixed results

SmartMeter deployment in the United States has not resulted in any noticeable reduction in consumption in households.

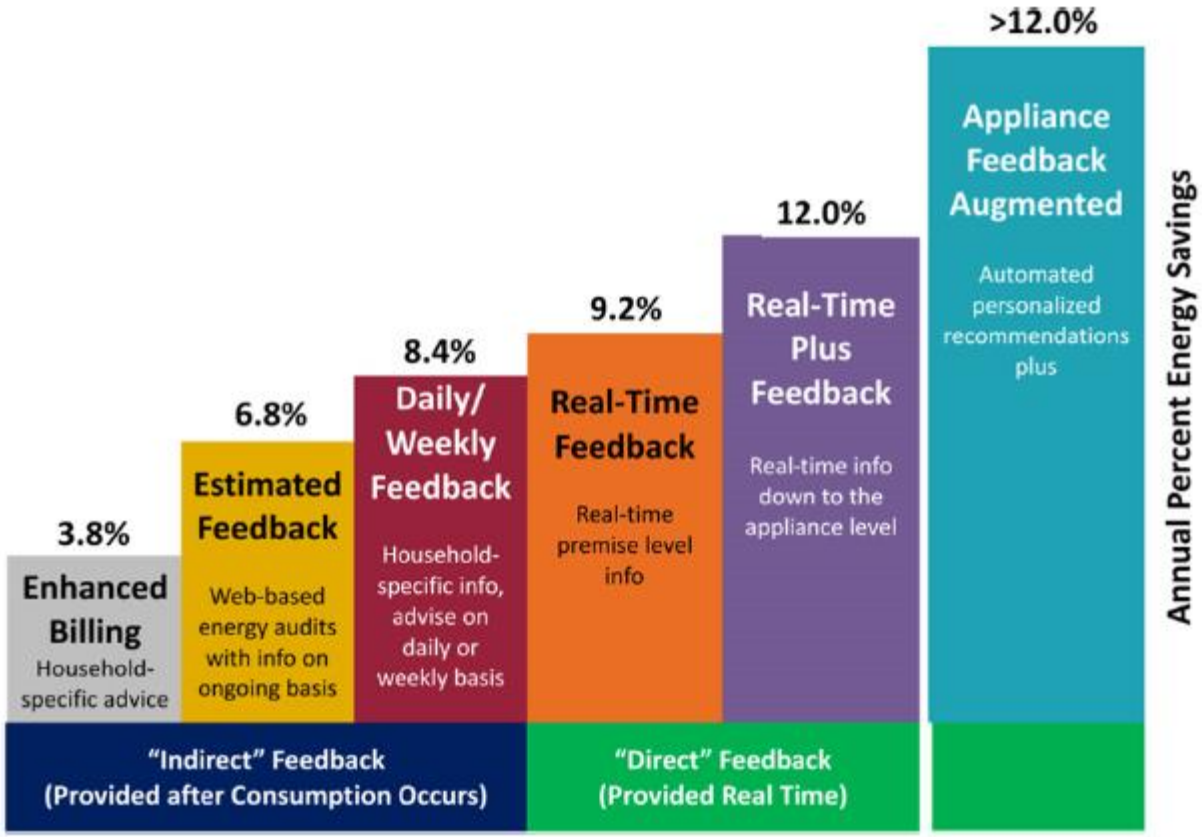
(as of 2011 there were 37 million SmartMeters in operation)

From: Armel et al, "Is disaggregation the holy grail of energy efficiency? The case of electricity", Energy Policy, 52, 2013.



From: «Ireland's SmartMeter rollout trial», SEAI, 2011

Feedback – the more the better?



Appliance level data has proved to be the key in providing effective feedback.

From: Armel et al, "Is disaggregation the holy grail of energy efficiency? The case of electricity", Energy Policy, 52, 2013.

The use of appliance level data

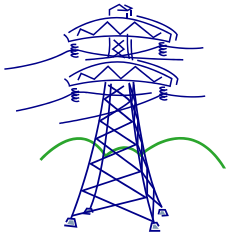
Appliance level feedback coupled with suggestions and goal setting was found to be more effective than feedback with just aggregated information.

Consumer: Reduction in consumption due to feedback.*

Example: "Using the right temperature for ironing can save energy! (last month you consumed 24 kWh in ironing)"

Appliance Manufacturers: Redesign, improve standards, marketing

Example: "How to combine steam and heat for lower energy consumption?"



Energy Supplier: Targeted marketing and load prediction

Example: "Offer lower rate to owners of electric heating systems if they decrease setpoint during night"

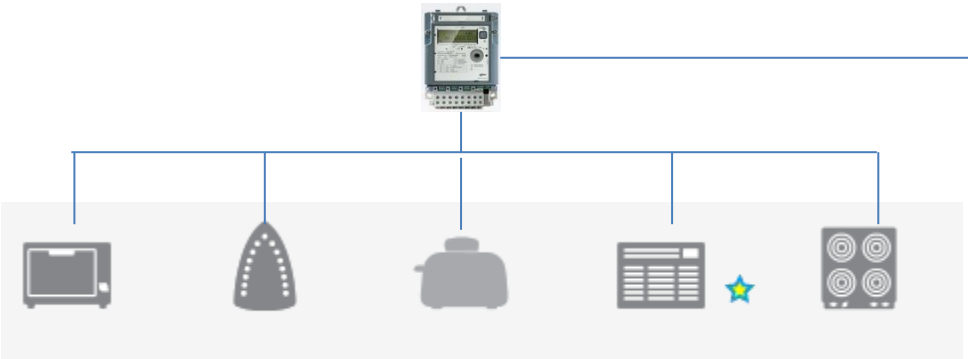
*Also for appliance health monitoring, security [Hart]

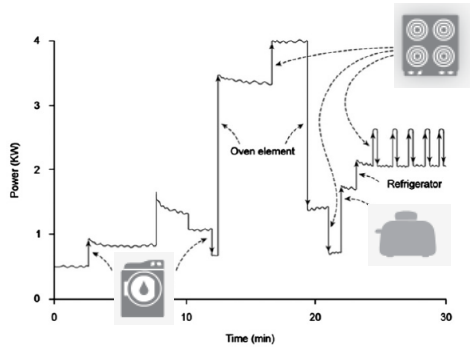
5. Getting appliance level energy data

How do we get appliance level data?

Intrusive : Measure at each appliance

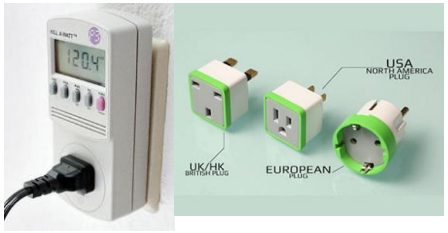
Non-Intrusive: Deduce from total load measurement





Intrusive Monitoring

Monitoring at the power outlet



+ The only available option for end users
- Expensive (for complete coverage of appliances)
- Difficult to install on modular kitchen appliances
- Not available for large currents
- Proprietary communication protocols

SmartAppliances

+ The ideal place – the appliance knows its state best!

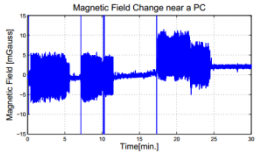
- Hardly any manufacturers
- Increased cost
- Lack of standards

Non-intrusive Monitoring

Most centralized meters provided by the electricity supplier are now some form of electronic devices with some communication interface (but slow)

Gradually there is a move towards adopting a more capable hardware (SmartMeters)

+

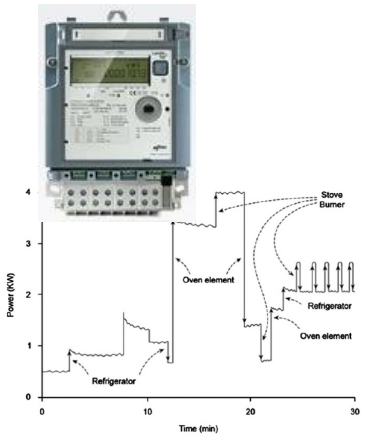


Appliance usage can be deduced by observing changes in electromagnetic fields in the home environment.

Sensors around home (light, sound etc.) can be used to deduce behaviour and hence energy consumption.

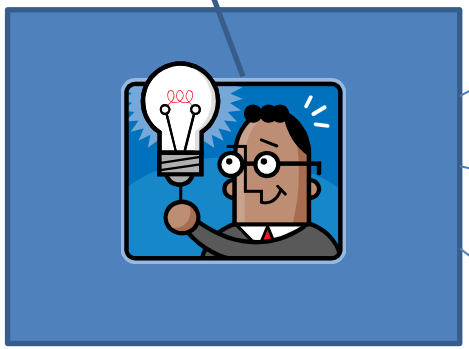
Getting appliance-level data

Non-intrusive appliance load monitoring

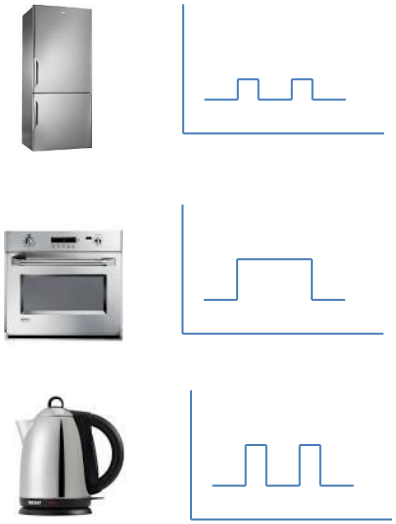


Whole house consumption

Disaggregation



Something clever



Individual appliance data

Appliance «Signature»

On / Off event information

Disaggregation

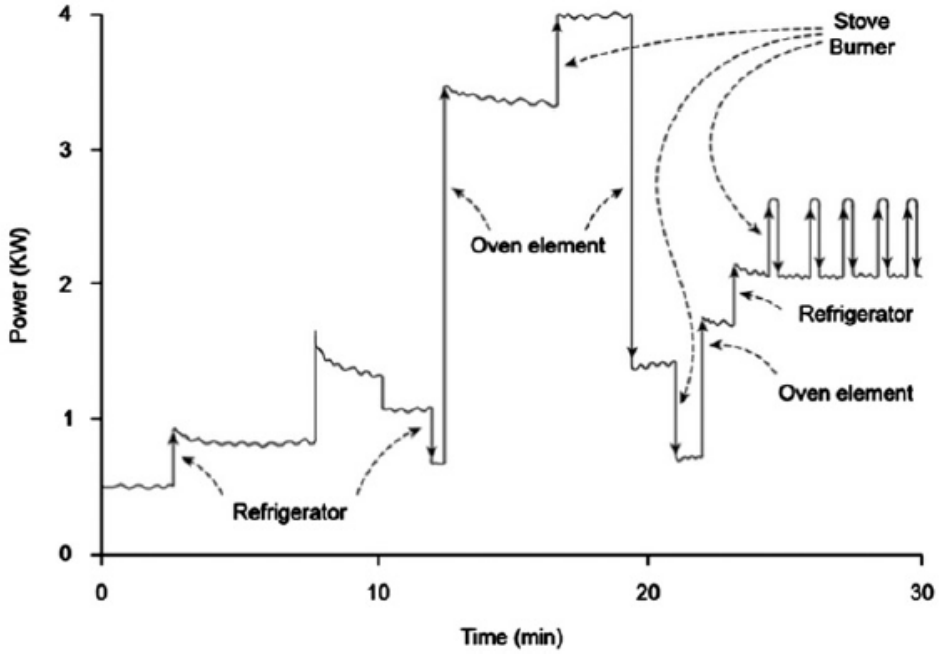
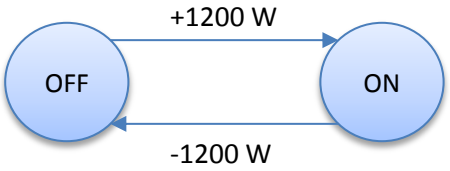


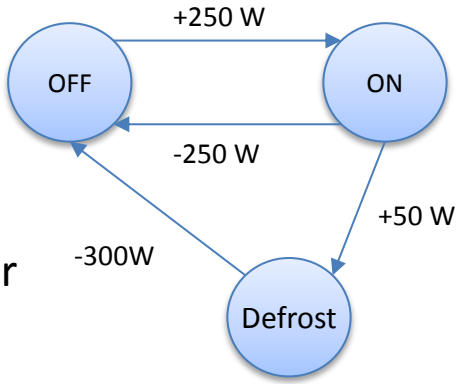
Image source : Hart, G., 1992. Nonintrusive appliance load monitoring. Proceedings of the IEEE 80 (12), 1870–1891

Disaggregation

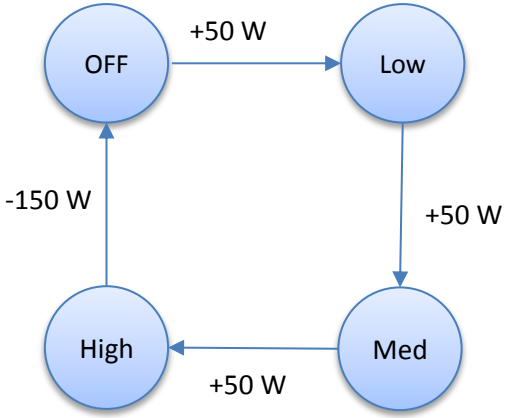
Appliance States



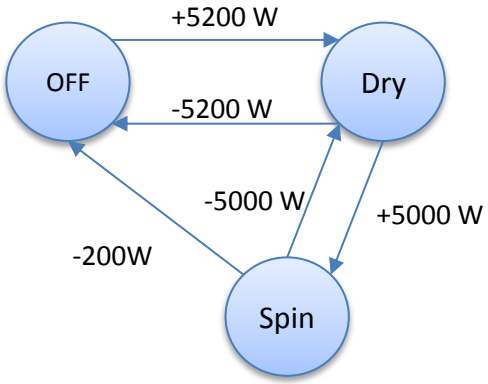
Toaster



Refrigerator



3-way Lamp



Clothes dryer

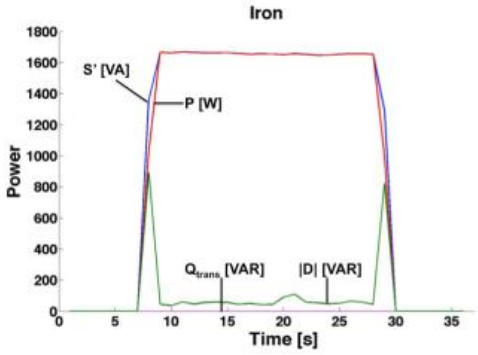
Adapted from : Hart, G., 1992. Nonintrusive appliance load monitoring. Proceedings of the IEEE 80 (12), 1870–1891

Disaggregation

“Signature” Types

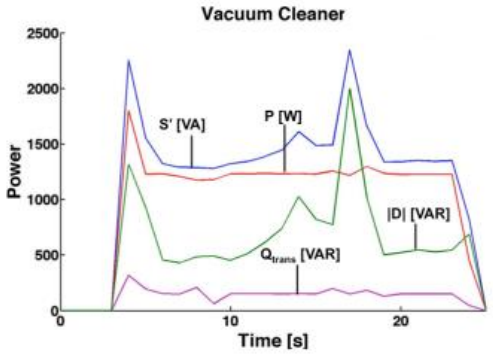
Steady-State

Power, Current..



Partly Transient

Shape, size, duration..



Transient

Frequency spectrum

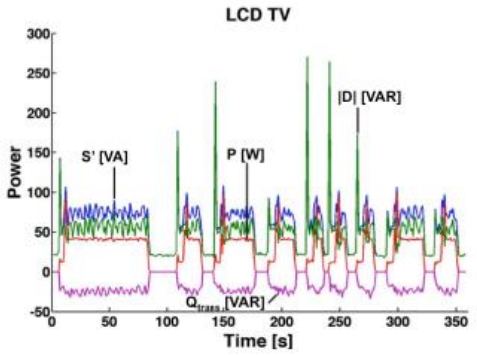
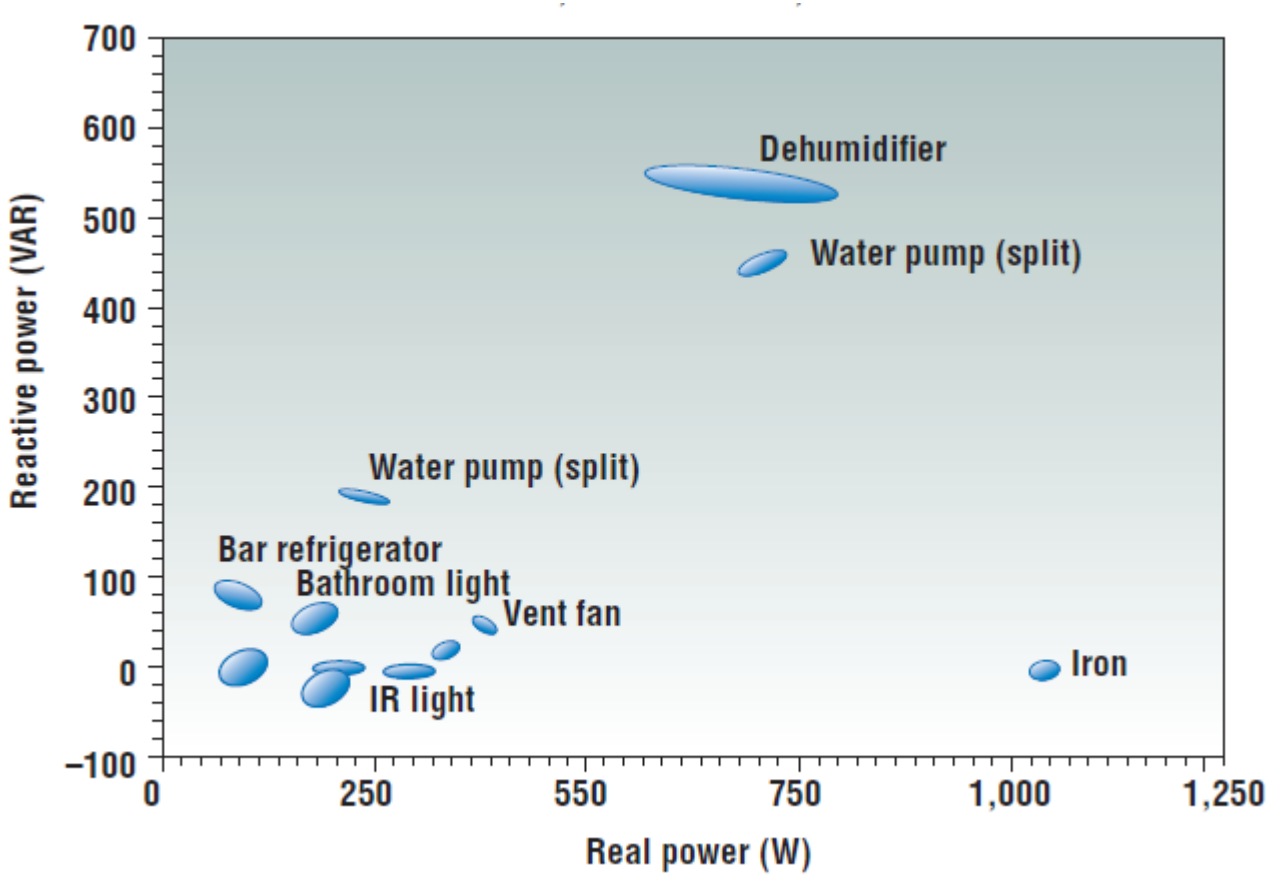


Image source : Hart, G., 1992. Nonintrusive appliance load monitoring. Proceedings of the IEEE 80 (12), 1870–1891

Weiss et. al 2012, Leveraging smart meter data to recognize home appliances. Proceedings of the IEEE International Conference on Pervasive Computing and Communications (PerCom 2012)

Disaggregation

Monitored parameters – how power vectors help



Disaggregation

Where to perform?

On the SmartMeter hardware

+ Reuse of hardware (processor, memory..)
+ Measurement data can be sampled in high frequency
- Requires firmware to be updated (on existing meters)
- Manufacturer specific solution

On a gateway device

+ Independent of meter manufacturer
+ Can be upgraded flexibly
- Network interface bottleneck for measurement
- Not all meters might have high-speed interface

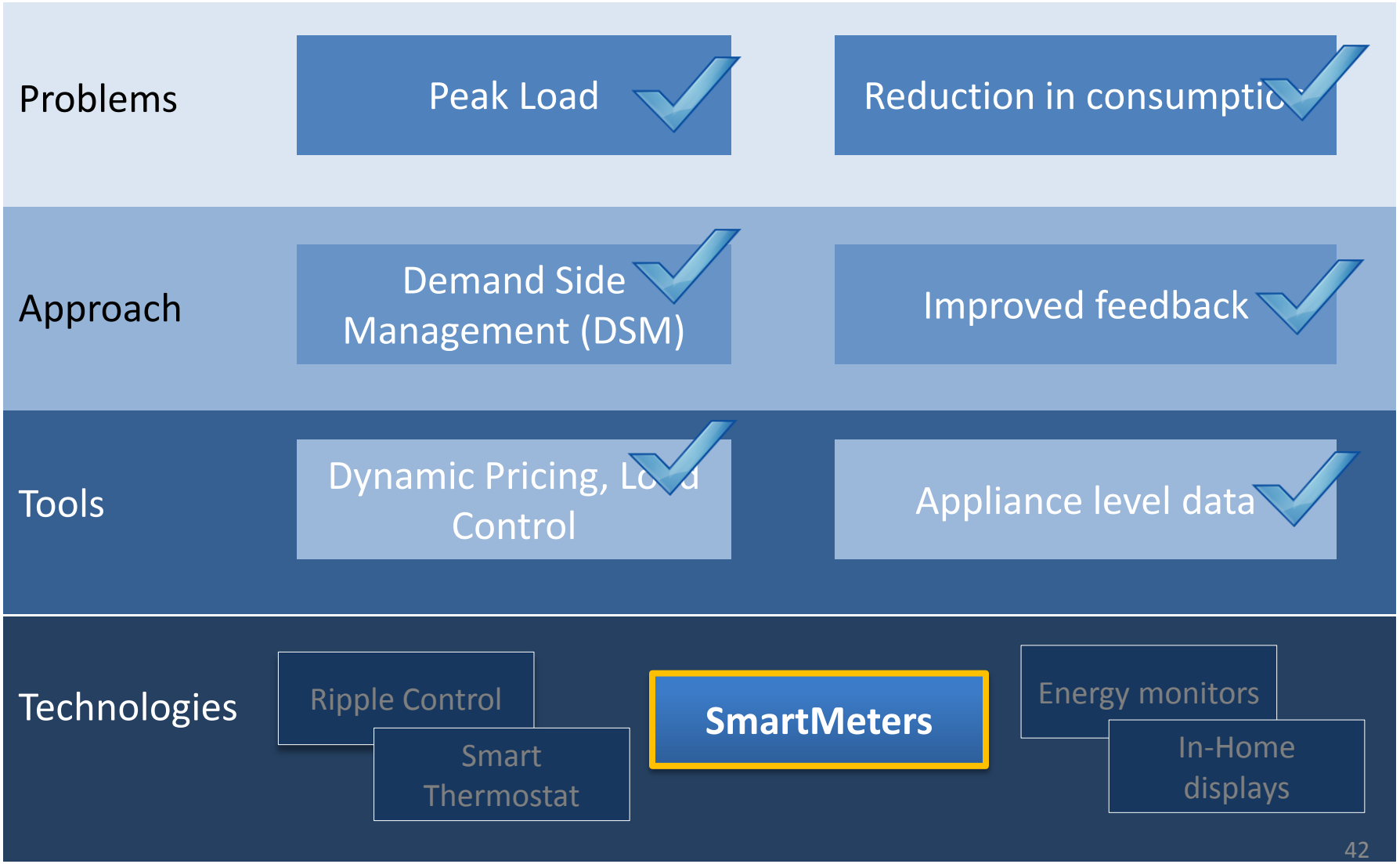
On a Cloud Server

+ Higher computing power (for more clever algorithms)
+ Easy to upgrade
- Transfer of measurement data over internet
- Privacy issues

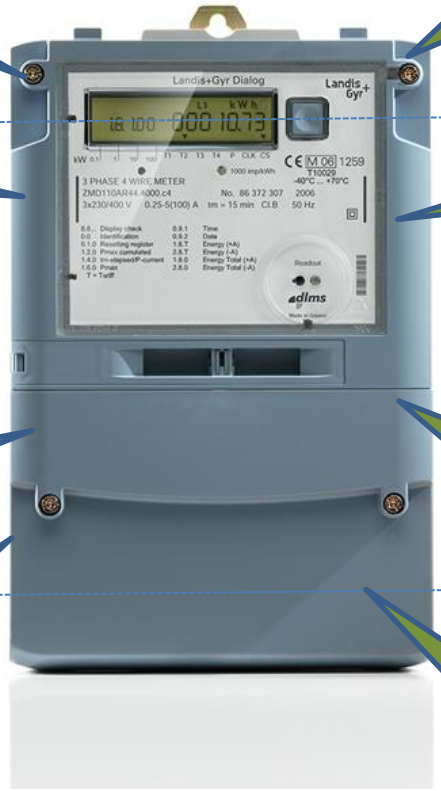
At the Utility (via WAN)

+ No internet connectivity required (no additional hardware)
- Slow communication channel

Where are we?


Problems
Peak Load
Reduction in consumption
Approach
Demand Side Management (DSM)
Improved feedback
Tools
Dynamic Pricing, Load Control
Appliance level data
Technologies
Ripple Control
Smart Thermostat
SmartMeters
Energy monitors
In-Home displays

SmartMeter as Gateway



Direct Load Control

Tell utility about participating appliances..

Information Gateway

Feedback to consumer, tell utility about loads..

Supplier

WAN

HAN

Customer

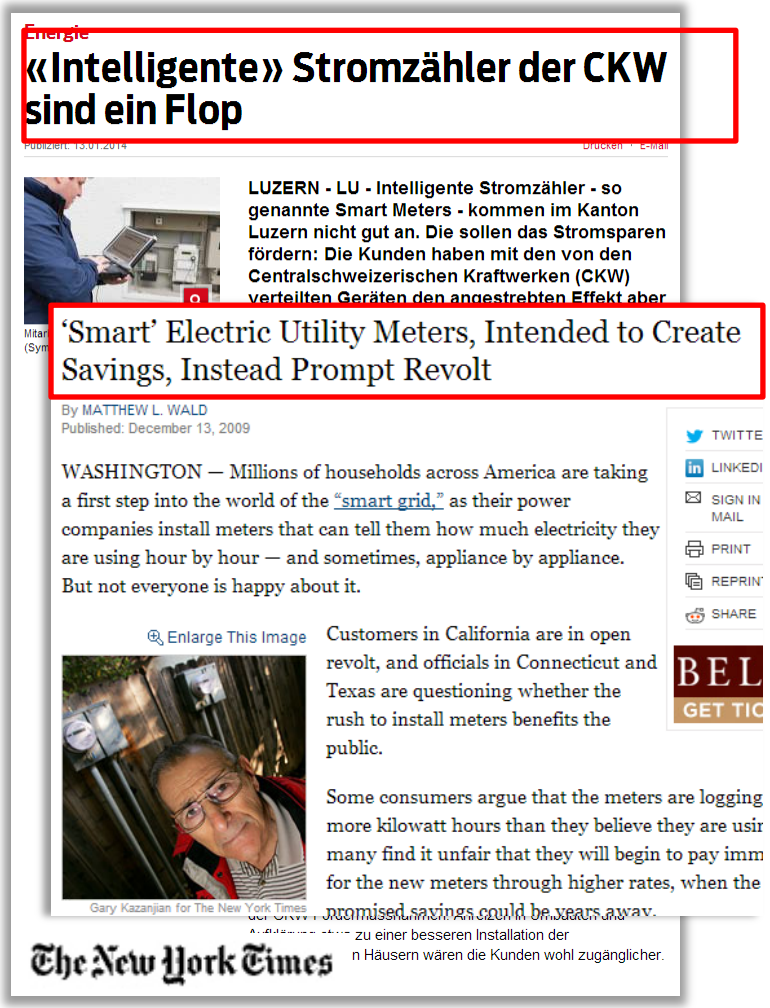
Dynamic Pricing

Pass on information to HAN devices, give feedback to utility

Billing data

Disaggregation

Why SmartMetering is not yet a success?



Energie

«Intelligente» Stromzähler der CKW sind ein Flop

Publiziert: 13.01.2014 Drucken E-Mail

LUZERN - LU - Intelligente Stromzähler - so genannte Smart Meters - kommen im Kanton Luzern nicht gut an. Die sollen das Stromsparen fördern: Die Kunden haben mit den von den Centralschweizerischen Kraftwerken (CKW) verteilten Geräten den angestrebten Effekt aber

Mitar
(Sym

'Smart' Electric Utility Meters, Intended to Create Savings, Instead Prompt Revolt

By MATTHEW L. WALD
Published: December 13, 2009

TWITTE
LINKEDI
SIGN IN MAIL
PRINT
REPRIN
SHARE

WASHINGTON — Millions of households across America are taking a first step into the world of the "smart grid," as their power companies install meters that can tell them how much electricity they are using hour by hour — and sometimes, appliance by appliance. But not everyone is happy about it.

Enlarge This Image

Gary Kazanjian for The New York Times

Customers in California are in open revolt, and officials in Connecticut and Texas are questioning whether the rush to install meters benefits the public.

Some consumers argue that the meters are logging more kilowatt hours than they believe they are usir many find it unfair that they will begin to pay imm for the new meters through higher raten, when the promised savings could be years away.

BEL
GET TIC

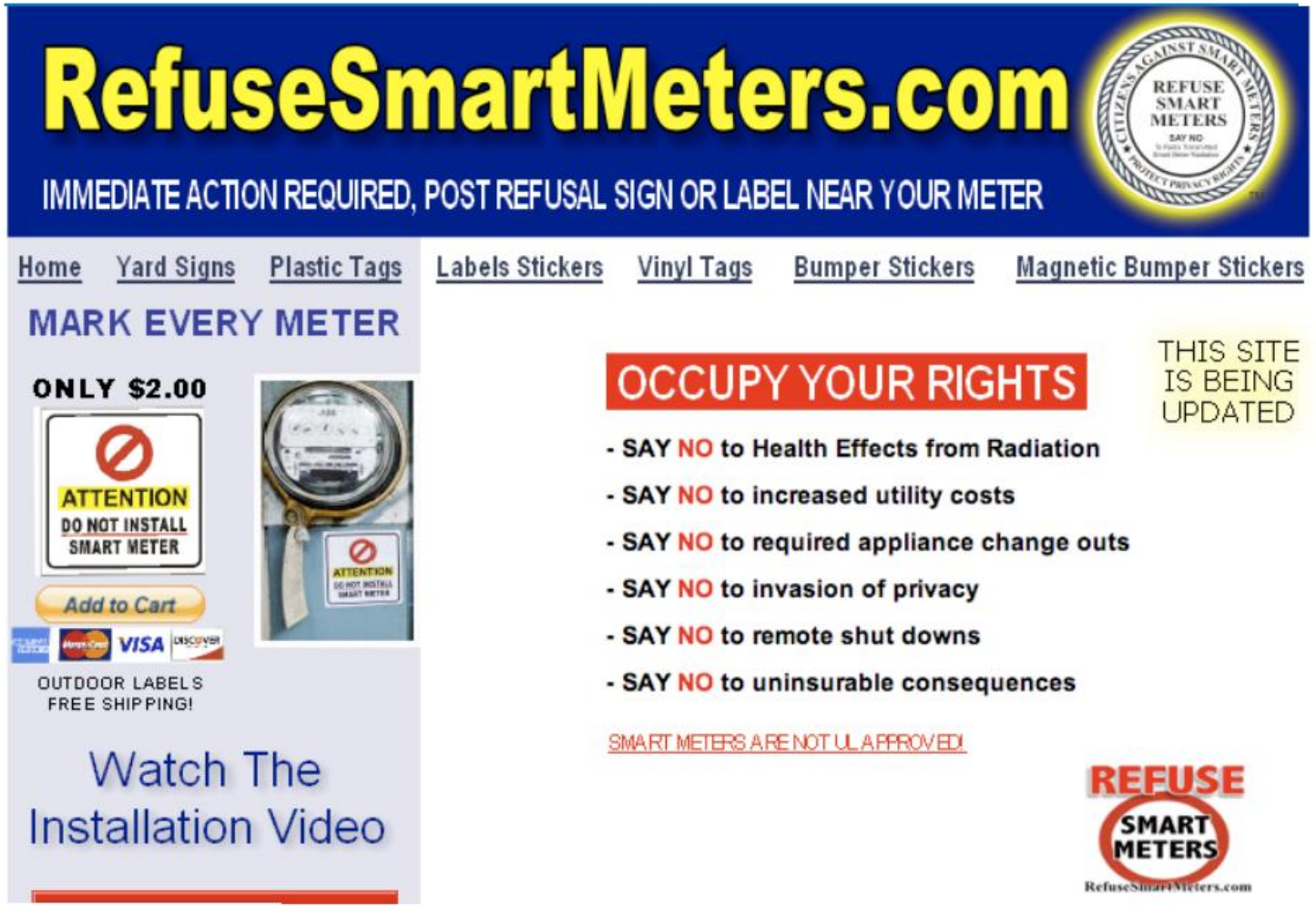
The New York Times

zu einer besseren Installation der
n Häusern wären die Kunden wohl zugänglicher.

- Utilities have largely used it for the purpose of «Automated Meter Reading» (AMR)
- Feedback without specific information, suggestions and goal-setting is only marginally effective.
- SmartMeter cannot be smart on its own – it needs to be a part of SmartEnergy system!

Example: PG & E spent nearly $2.2 billion in SmartMeter rollout in Bakersfiled CA, but failed to provide its customers information on dynamic pricing it implemented via SmartMeters. As a result, customers were not aware that they were using power during peak tariffs!

Privacy Issues



[refusesmartmeters.com]

Conclusion

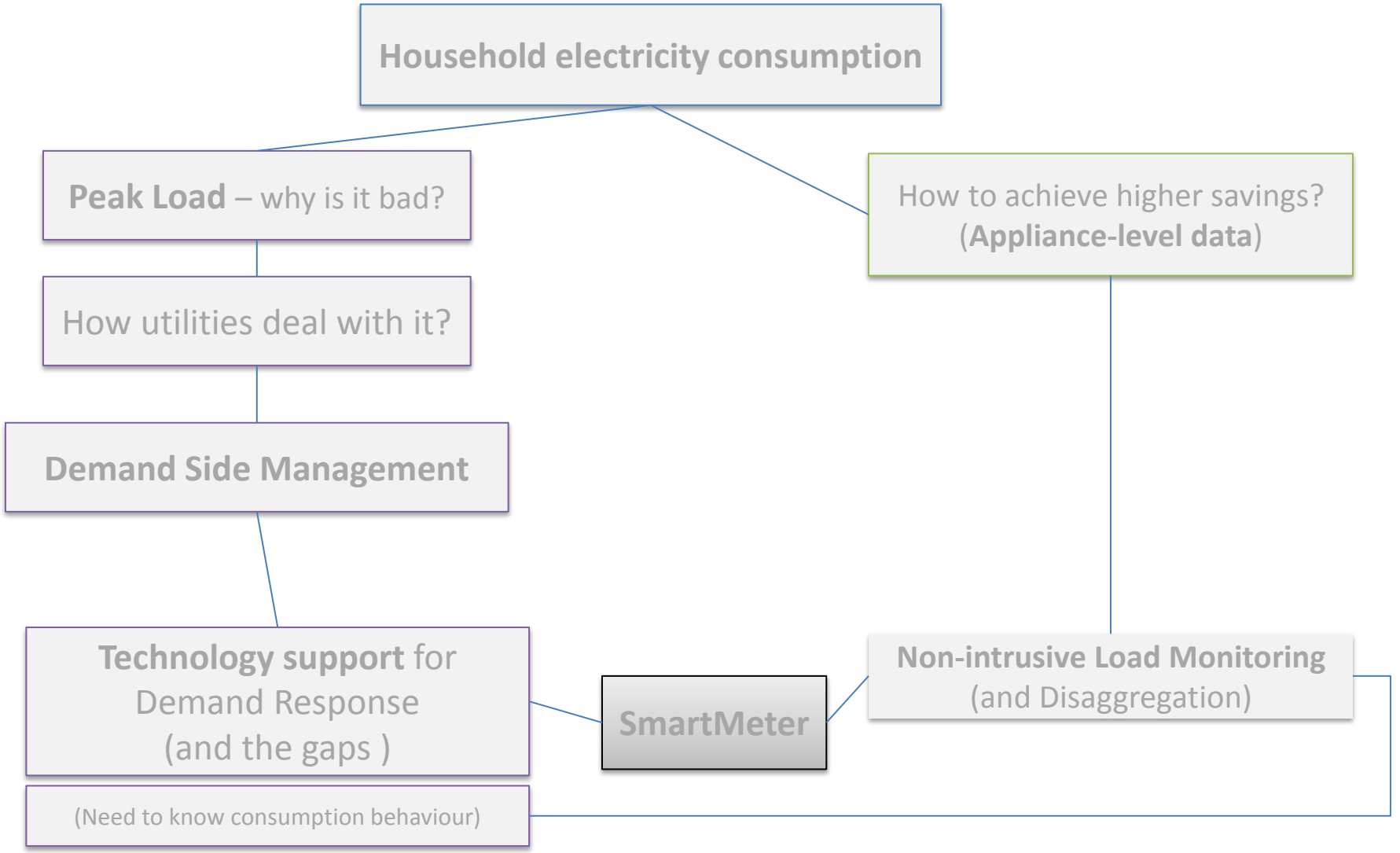
Demand Side Management is an interesting mix of energy management and information technology.

There is an exciting possibility to achieve energy savings in households by cleverly applying pervasive computing.

Existing elements like SmartGrid, SmartMetering and SmartAppliance need to function coherently – which would then lead to the state of **SmartEnergy**.

If you liked this topic, you might also consider visiting http://www.vs.inf.ethz.ch/res/

We are done!


Household electricity consumption
Peak Load – why is it bad?
How utilities deal with it?
Demand Side Management
How to achieve higher savings? (Appliance-level data)
Technology support for Demand Response (and the gaps)
SmartMeter
Non-intrusive Load Monitoring (and Disaggregation)
(Need to know consumption behaviour)

Backup: Everything Smart

Origin

OLD ENGLISH

smeortan

GERMAN

schmerzen

→ smart

Old English *smeortan* (verb); related to German *schmerzen* ; the adjective is related to the verb, the original sense (late Old English) being 'causing sharp pain'; from this arose 'keen, brisk,' whence the current senses of 'mentally sharp' and 'neat in a brisk, sharp style.'

Translate smart to Choose language

Use over time for: smart

Backup: Privacy Issues

Zuger Datenschützer

Warnung vor «Nebenwirkung» intelligenter Stromzähler

Schweiz 24. April 2013, 14:43

Zunehmend sollen auch in der Schweiz Haushalte mit intelligenten Stromzählern ausgerüstet werden. Doch die «smarten» Geräte können ungewollt viel preisgeben.

(sda) Der Datenschützer des Kantons Zug, René Huber, mahnt im Umgang mit sogenannten Smart Meters zur Vorsicht. Das ständige detaillierte Erfassen des Stromverbrauchs mache das Leben im einzelnen Haushalt weitgehend durchsichtig. Die Daten müssten laut Huber anonymisiert werden.

Der transparente Tagesablauf

Familie Müller pflegt kurz nach 7 Uhr morgens aufzustehen, Herr Meier trinkt gern einen Tee oder eine heisse Milch, bevor er um 23 Uhr 30 das Licht löscht, Frau Schmid hat häufig spätabends Besuch und macht zweimal im Jahr mehrere Wochen Ferien.

Solche und ähnliche Erkenntnisse ermöglichen die neuen digitalen Stromzähler, die nun auch im Kanton Zug Einzug halten sollen – die sogenannten Smart Meters. Die Informationen werden den einzelnen Kunden gleich mitgeteilt. Ziel ist, Strom zu sparen. Allerdings sei damit auch das «gläserne Leben» vorprogrammiert, meint der Zuger Datenschützer warnend. Obendrein sei der Spareffekt minimal.

Daten erfassen aus der Ferne

Es sei verständlich, dass die Wasserwerke Zug (WWZ) auf das «Fernablesen» umstellen und nicht mehr in jeden Haushalt einen Stromableser schicken wollten, sagte Huber zur Nachrichtenagentur SDA. Den WWZ sei auch nicht an den privaten Details gelegen – «die WWZ sind kein Daten-Krake»: Aber wo Daten erhoben würden, würden sie auch ausgewertet.

Zuger Smart Meter App

Mehr von diesem Entwickler

von magspin ag

Öffnen Sie iTunes, um Apps zu kaufen und zu laden.

In iTunes ansehen

Gratis

Kategorie: Wirtschaft
Erschienen: 21.11.2012
Version: 1.2
Größe: 4.5 MB
Sprachen: Deutsch, Englisch
Entwickler: magspin ag
© 2012 magspin ag
Kennzeichnung: 4+

Kompatibilität: Erfordert iOS 5.0 oder neuer. Kompatibel mit iPhone, iPad und iPod touch. Diese App ist für iPhone 5 optimiert.

Kundenbewertungen

Wir haben noch nicht genügend Bewertungen erhalten, um einen Durchschnittswert für die aktuelle Version dieses Artikels anzeigen zu können.

Weitere iPhone Apps von magspin ag

magspin dashboard

Beschreibung

Die Smart-Meter-App der Energiestadt Zug und der Wasserwerke Zug AG (WWZ) ist Ihr Energieportal für zu Hause.

Damit haben Sie Ihren aktuellen Stromverbrauch immer im Blick und erhalten Statistiken zu Ihrem Energiekonsum der

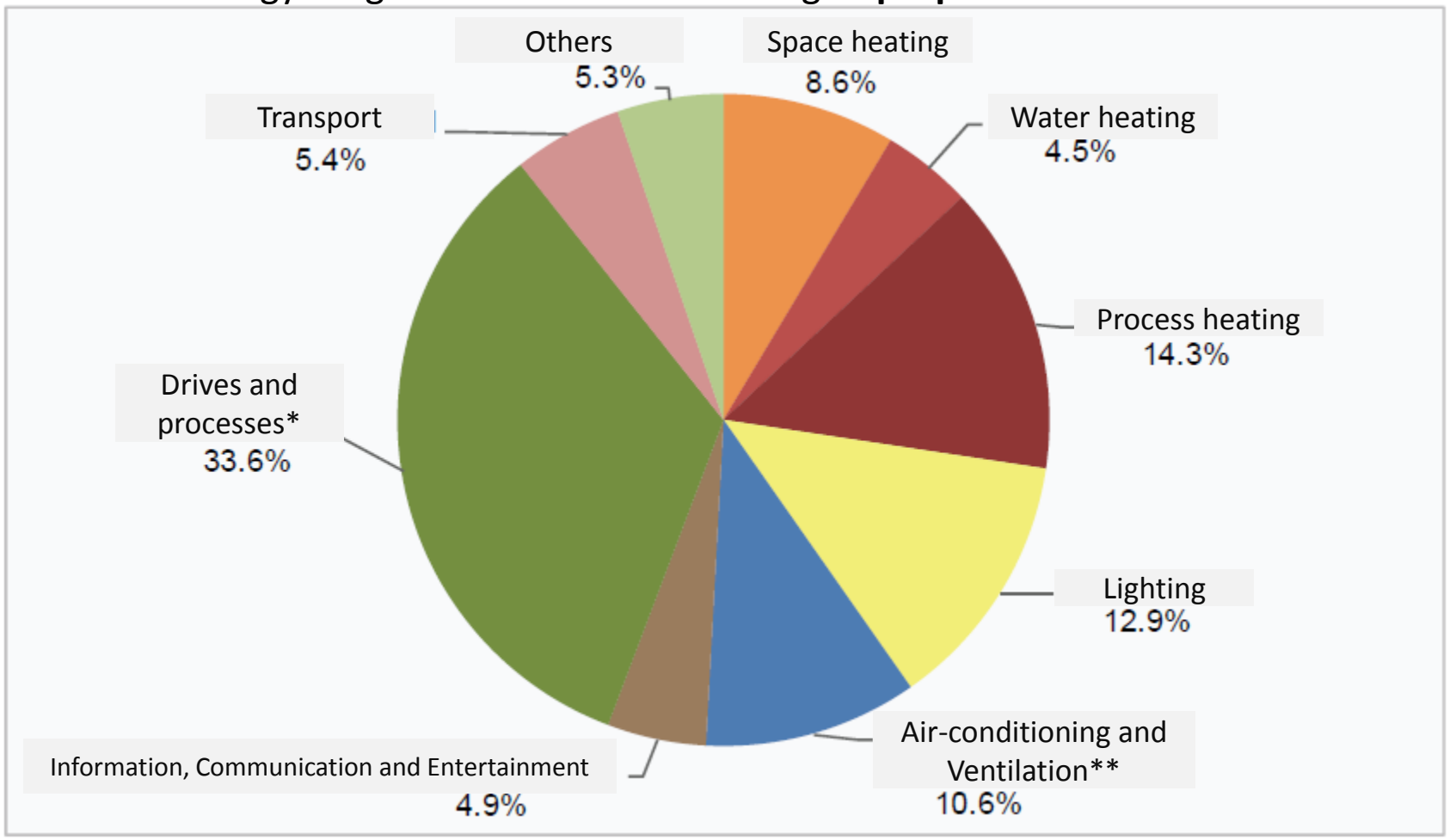
Zuger Smart Meter App Support ▸

...Mehr

iPhone Screenshots

Energy Statistics

Electrical Energy usage in Switzerland according to **purpose**

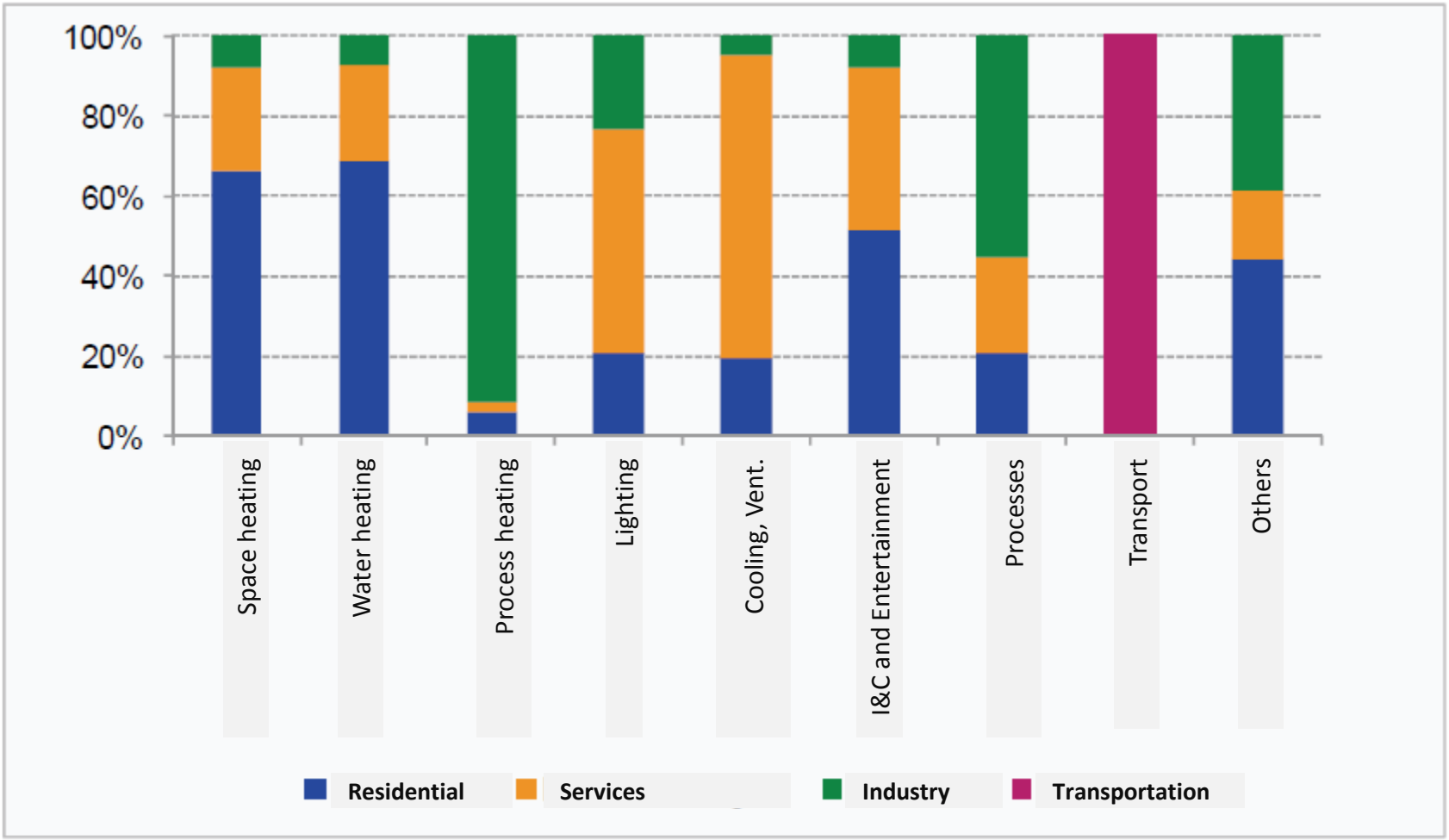


*Includes washing, drying, freezing, cooling, electrical tools, industrial manufacturing, water purification and agricultural equipment.
**Includes cooling for data servers

Source : Schweizerische Elektrizitätsstatistik 2012, BFE

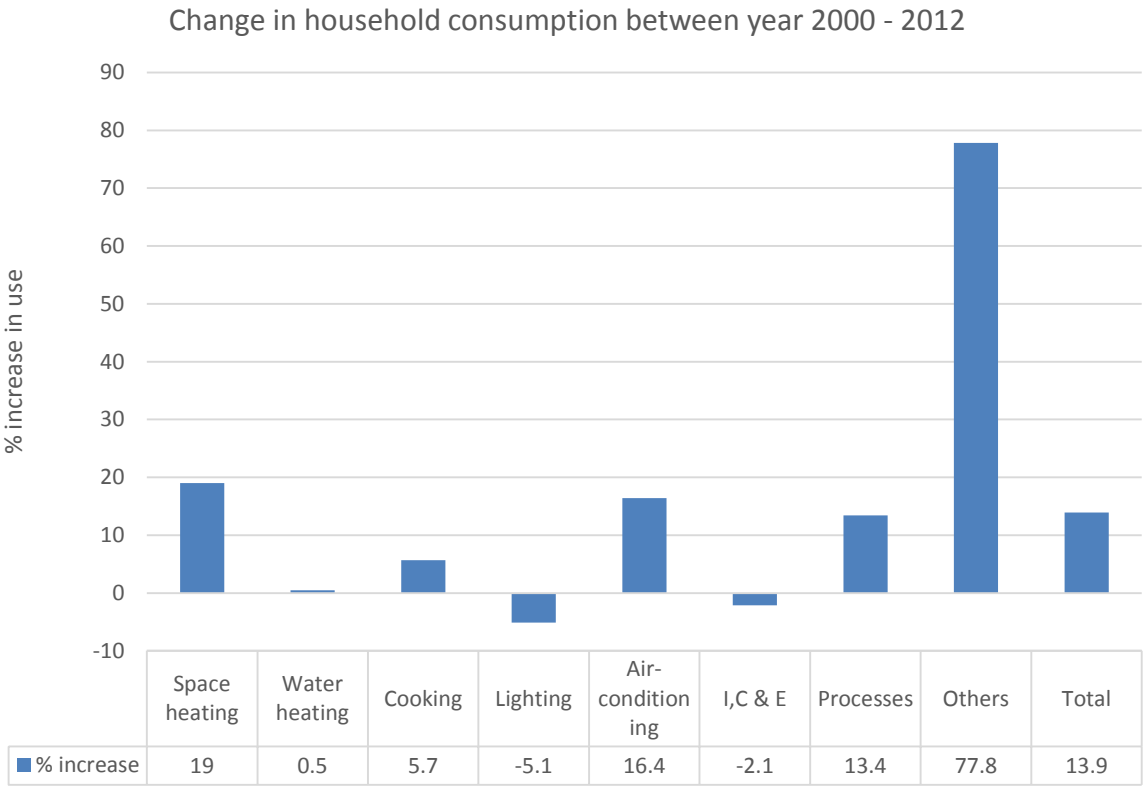
Energy Statistics

Electrical Energy usage in Switzerland according to purpose across sectors



Source : Schweizerische Elektrizitätsstatistik 2012, BFE

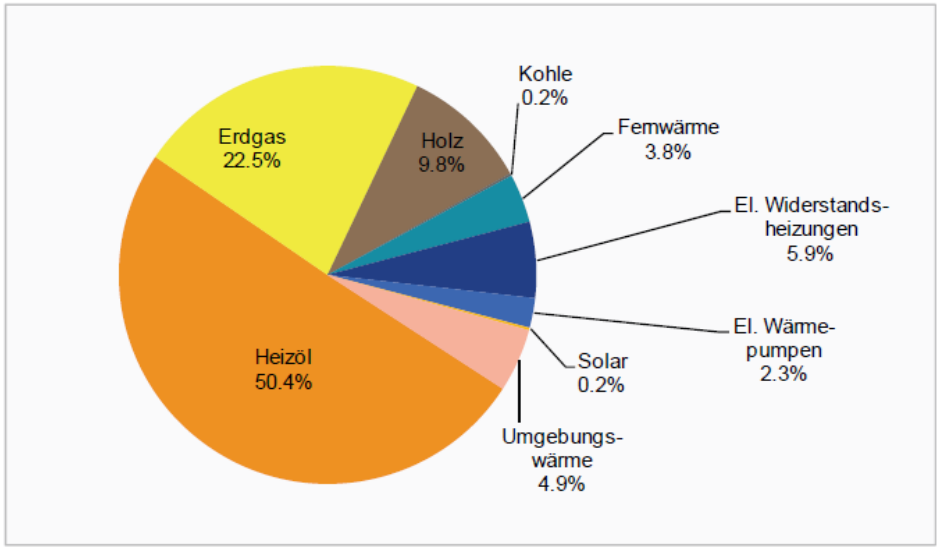
Energy Statistics



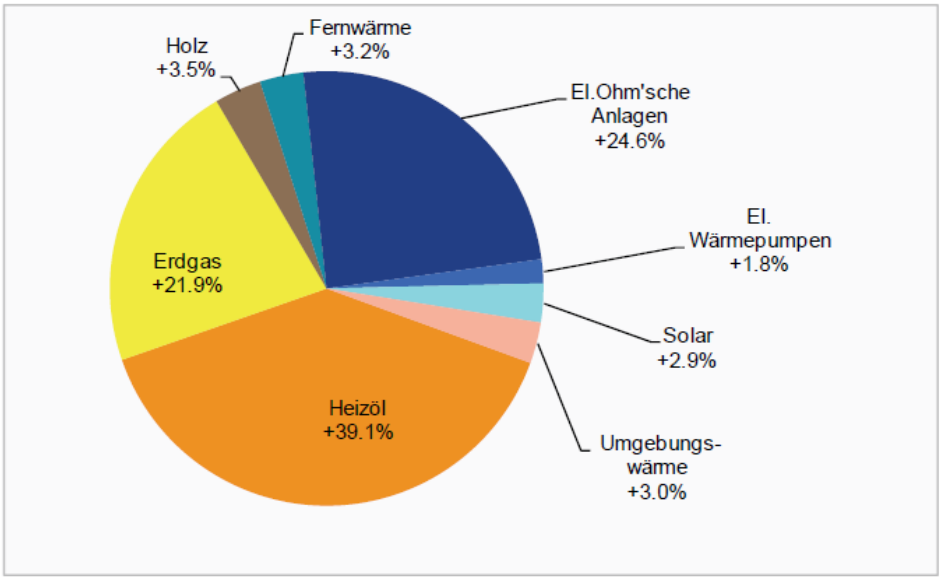
Backup

Energy source - households

Space heating

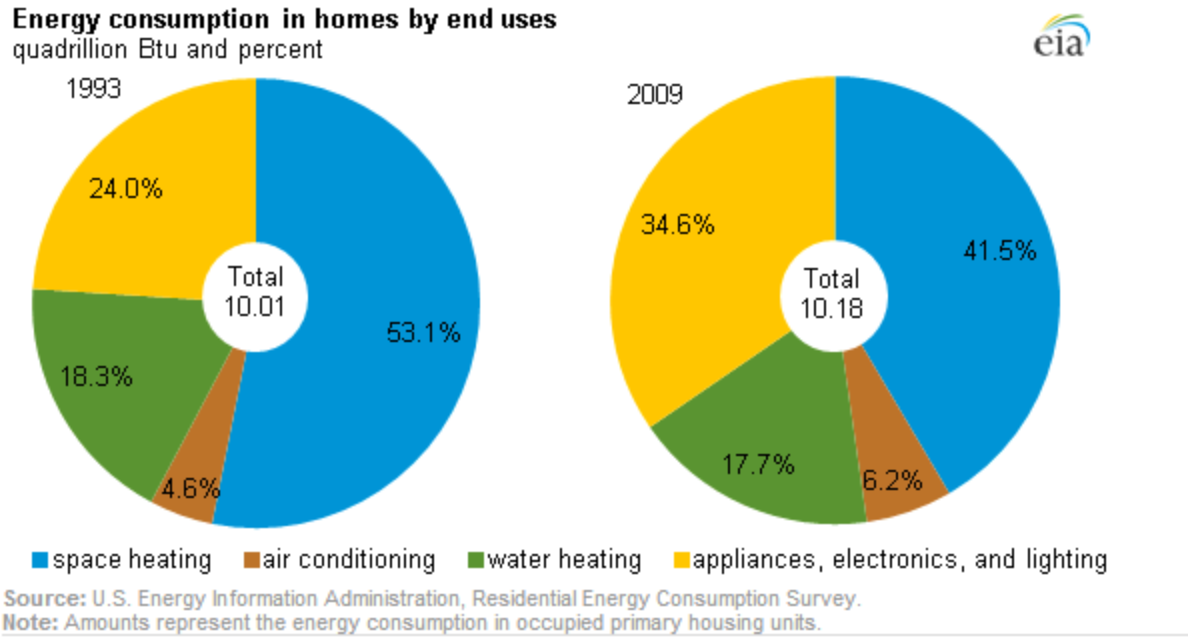


Water heating



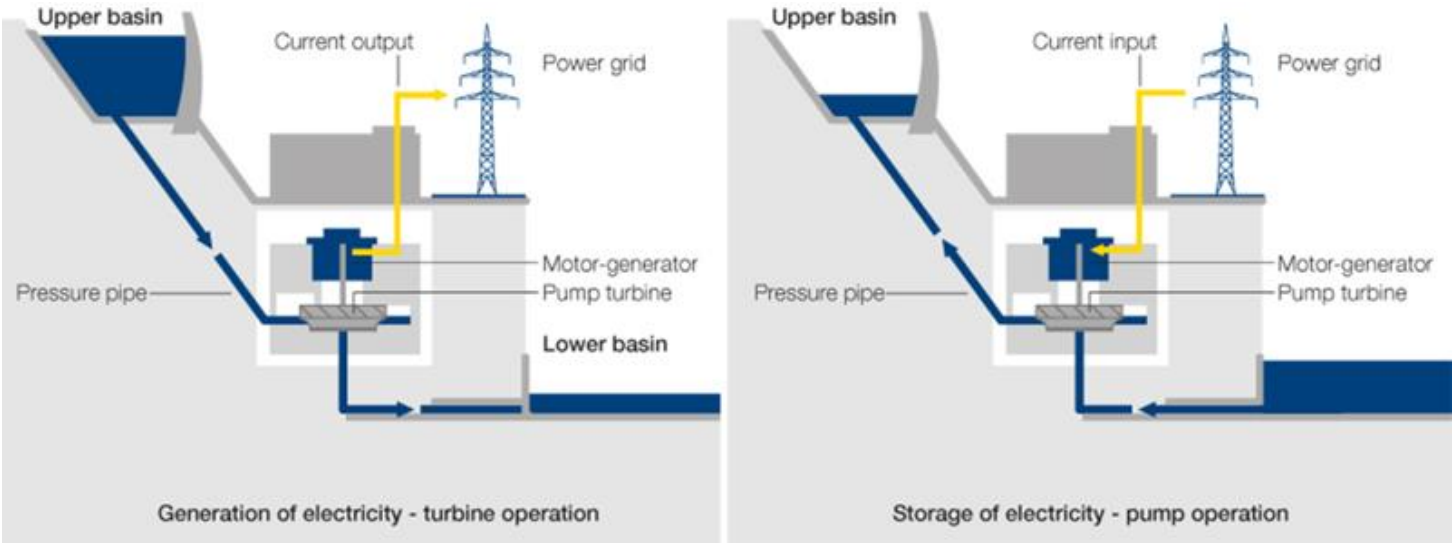
Energy Statistics

Electrical Energy usage in the U.S.A in **residential sector**



Storage

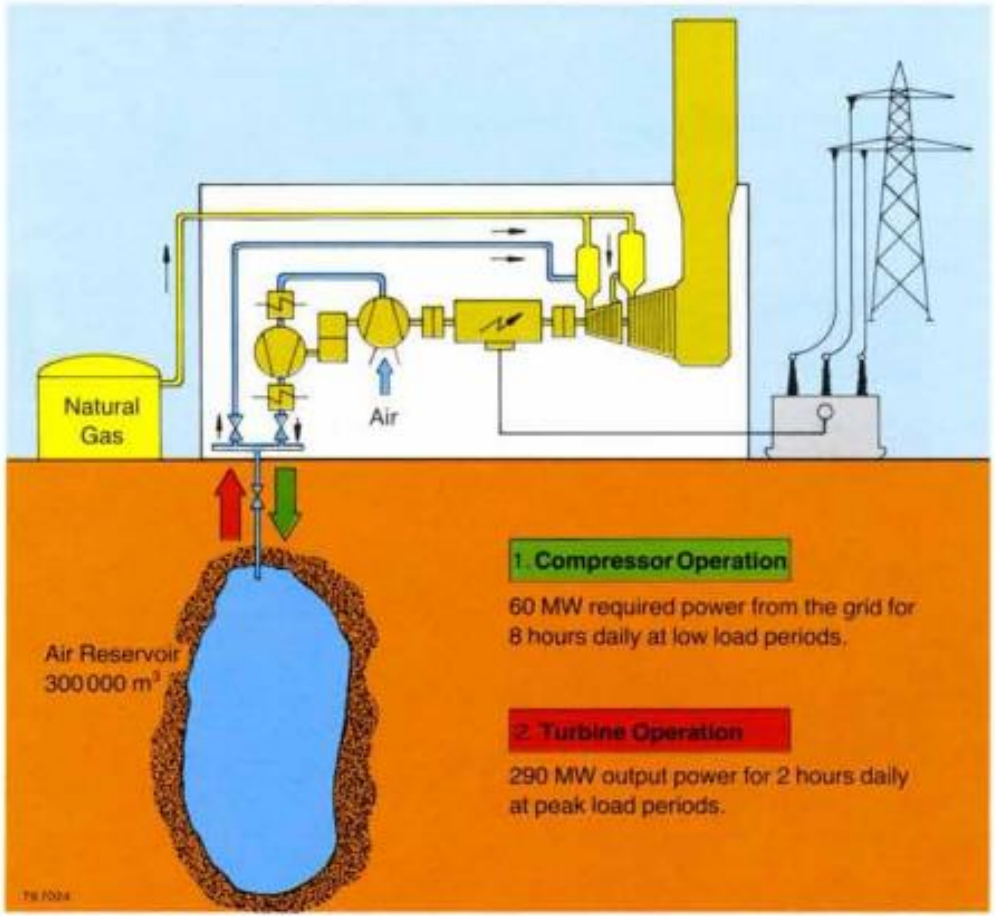
Centralized Storage – Pumped Storage



Source : www.thehea.org

Storage

Centralized Storage – Compressed air



Source : www.eon.com

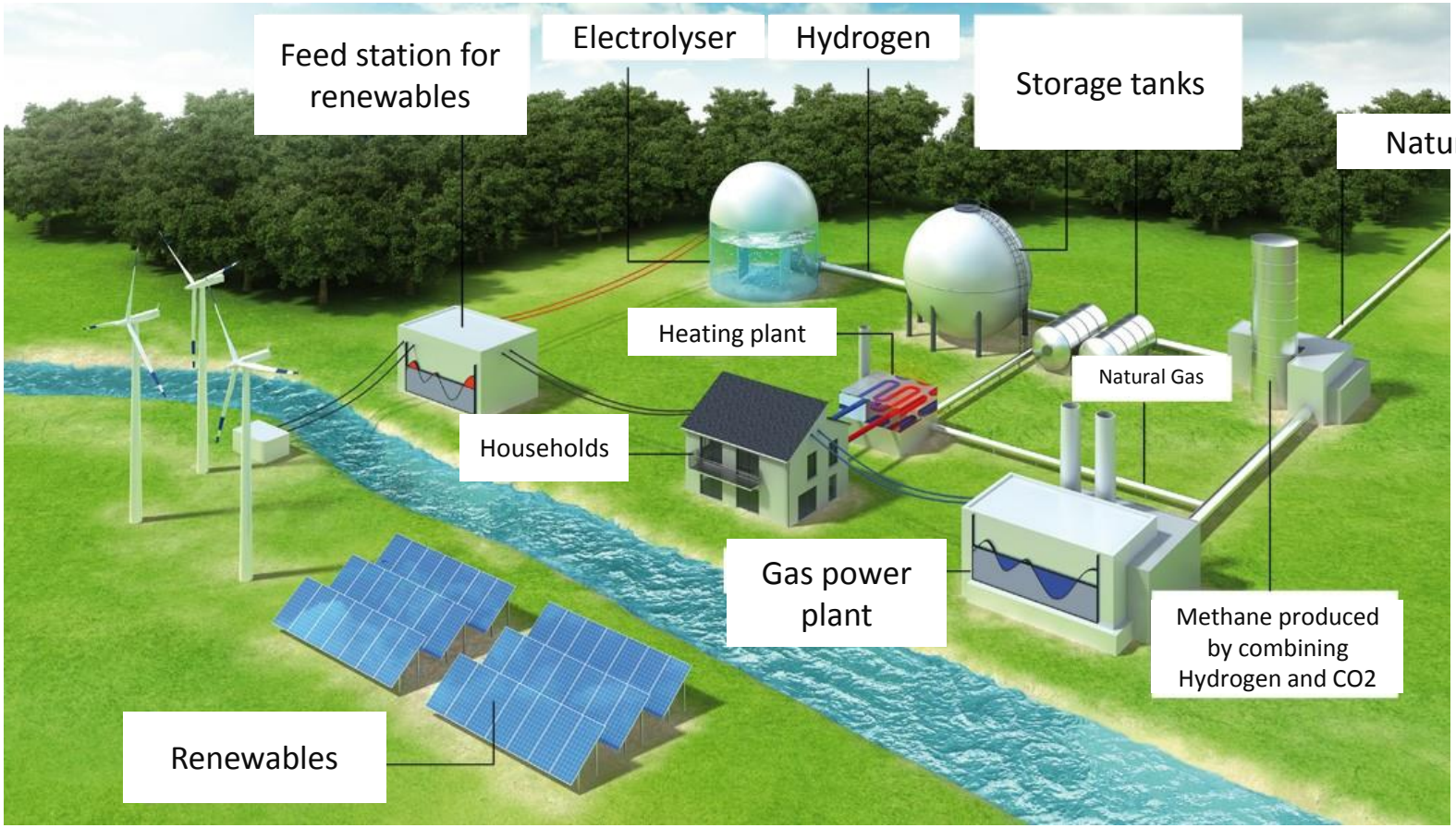
Storage

Centralized Storage - Batteries

Source : www.eon.com

Storage

Centralized Storage – Power-to-Gas



Source : EnBW AG – www.enbw.com

Storage

Distributed Storage

Using Plug-in Electric Vehicles (PEVs)

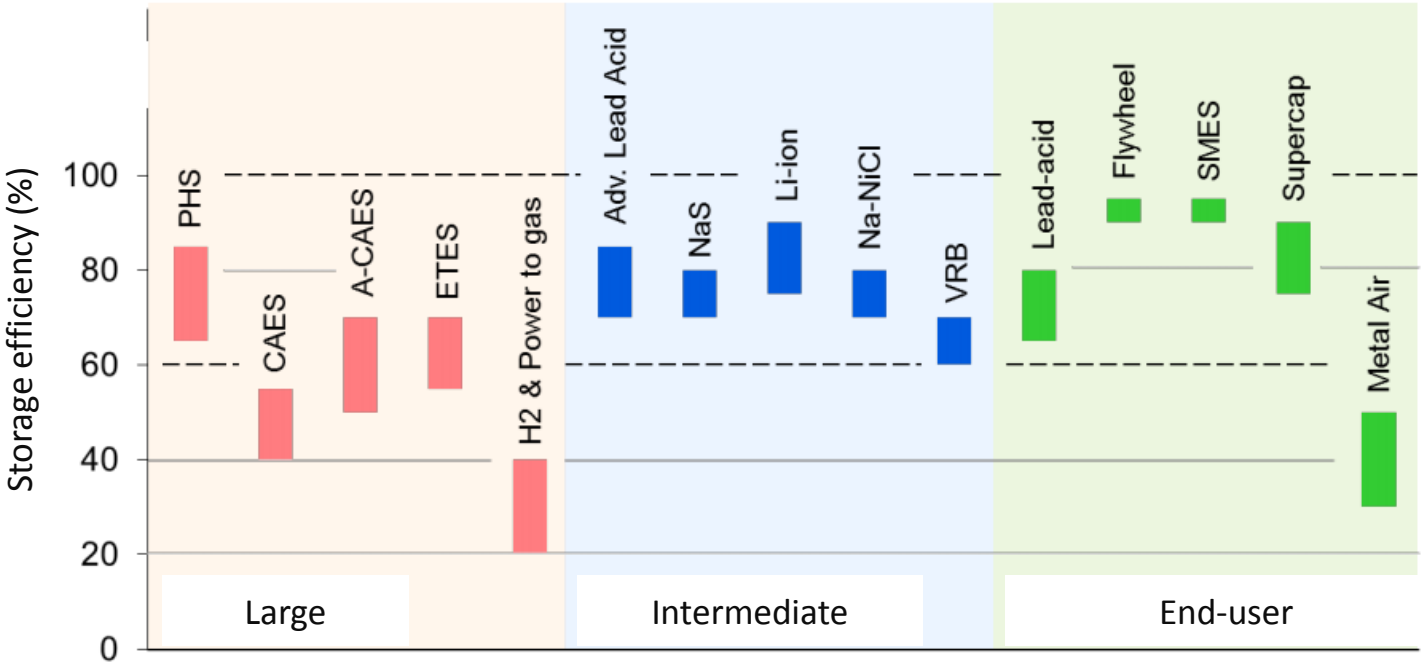
Battery (Li-ion) Storage (also coupled with solar generation)

+ **Can be used to improve quality of supply**
- Expensive
- Needs to have intelligent charging method and tariff plans

Source : EnBW AG – www.enbw.com

Storage

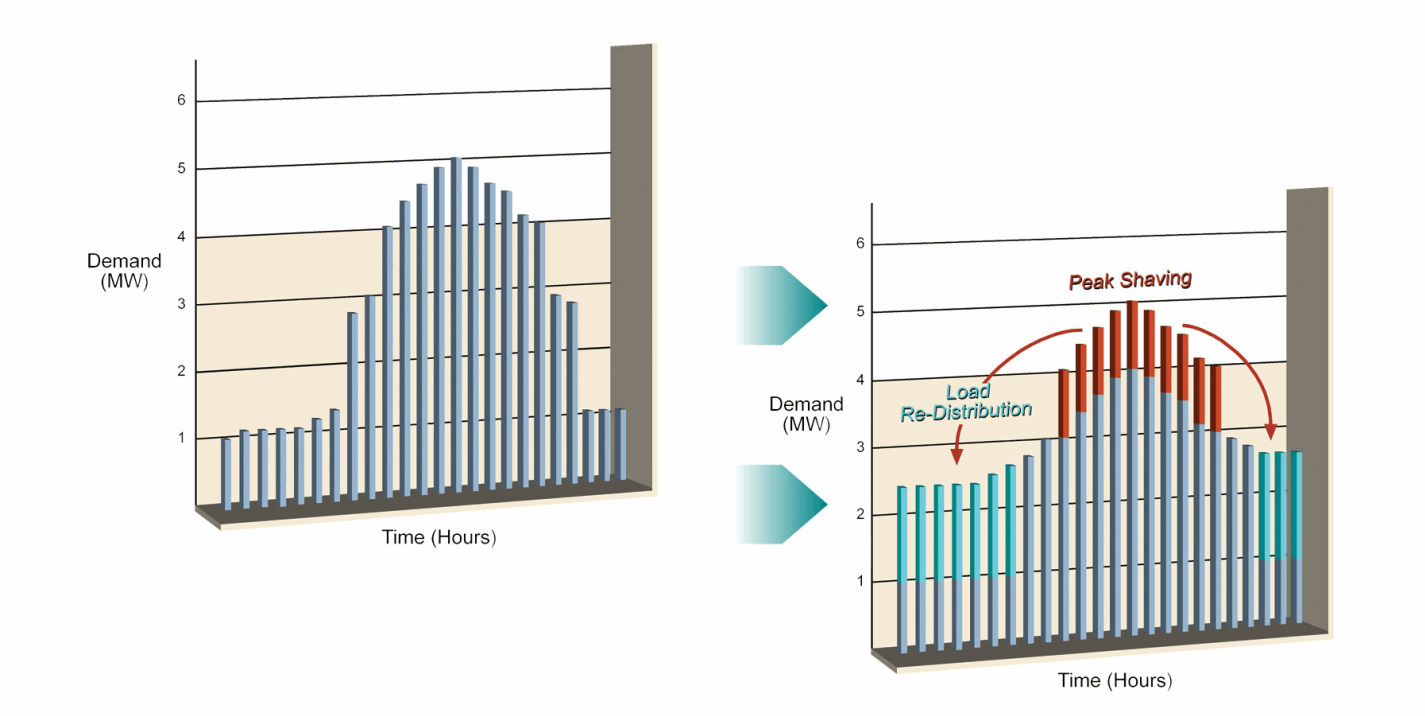
Storage is not only expensive, but also inefficient



PHS: Pumped hydraulic storage
CAES: Compressed air energy storage
A-CAES: Adiabtic compressed air storage
ETES: Electro-thermal energy storage
VRB: Vanadium redox battery
SMES: Superconducting magnetic energy storage

Source : EnBW AG – www.enbw.com

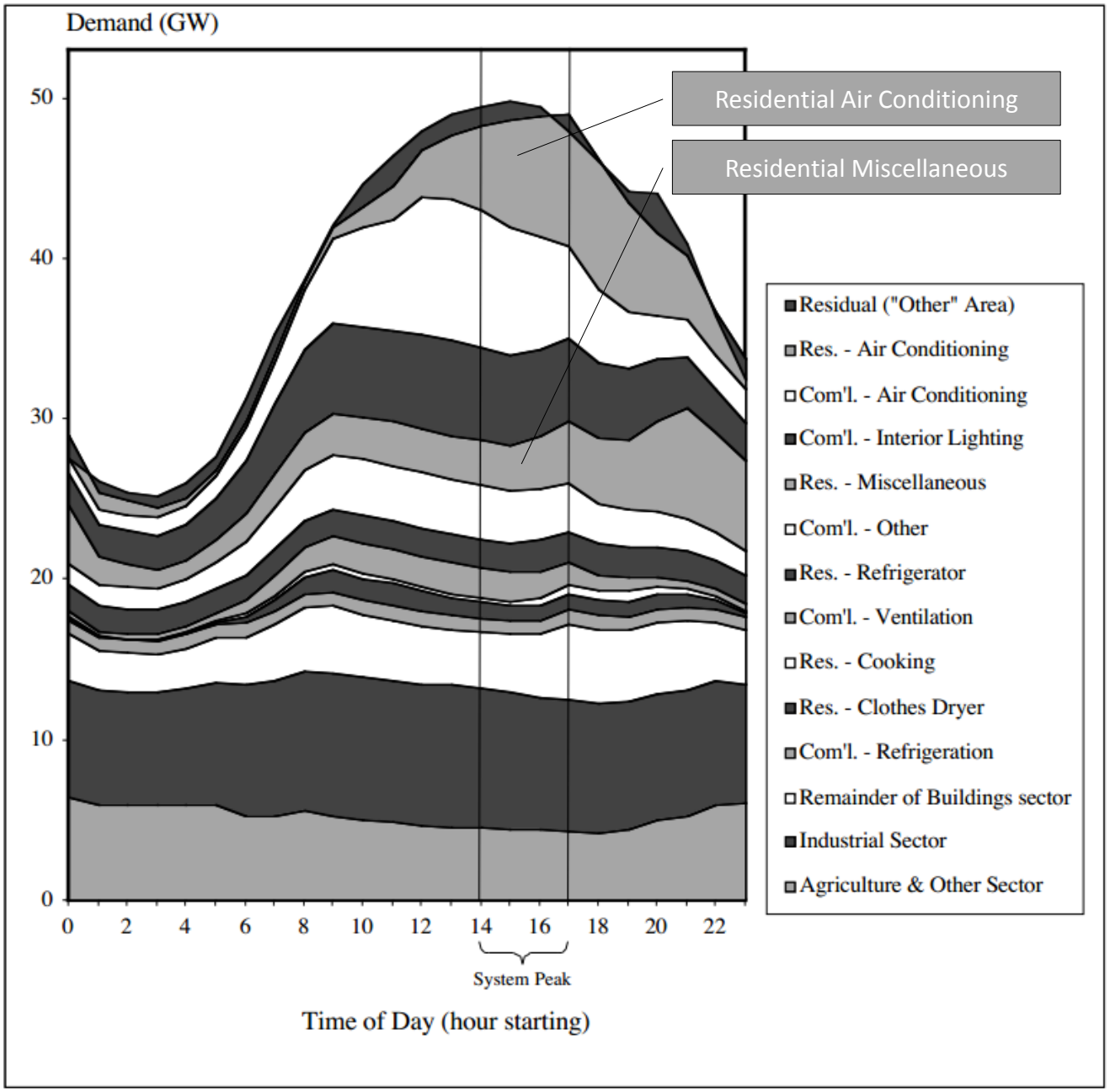
Redistributing the peak



Encourage consumers to shift their usage – either by price incentive or direct load control (also with some incentive)

Image source : www.Wikipedia.org

Distribution of load causes during the peak period



Demand Response

Other uses

Helps reduce electricity price by having predictable transactions on the energy markets

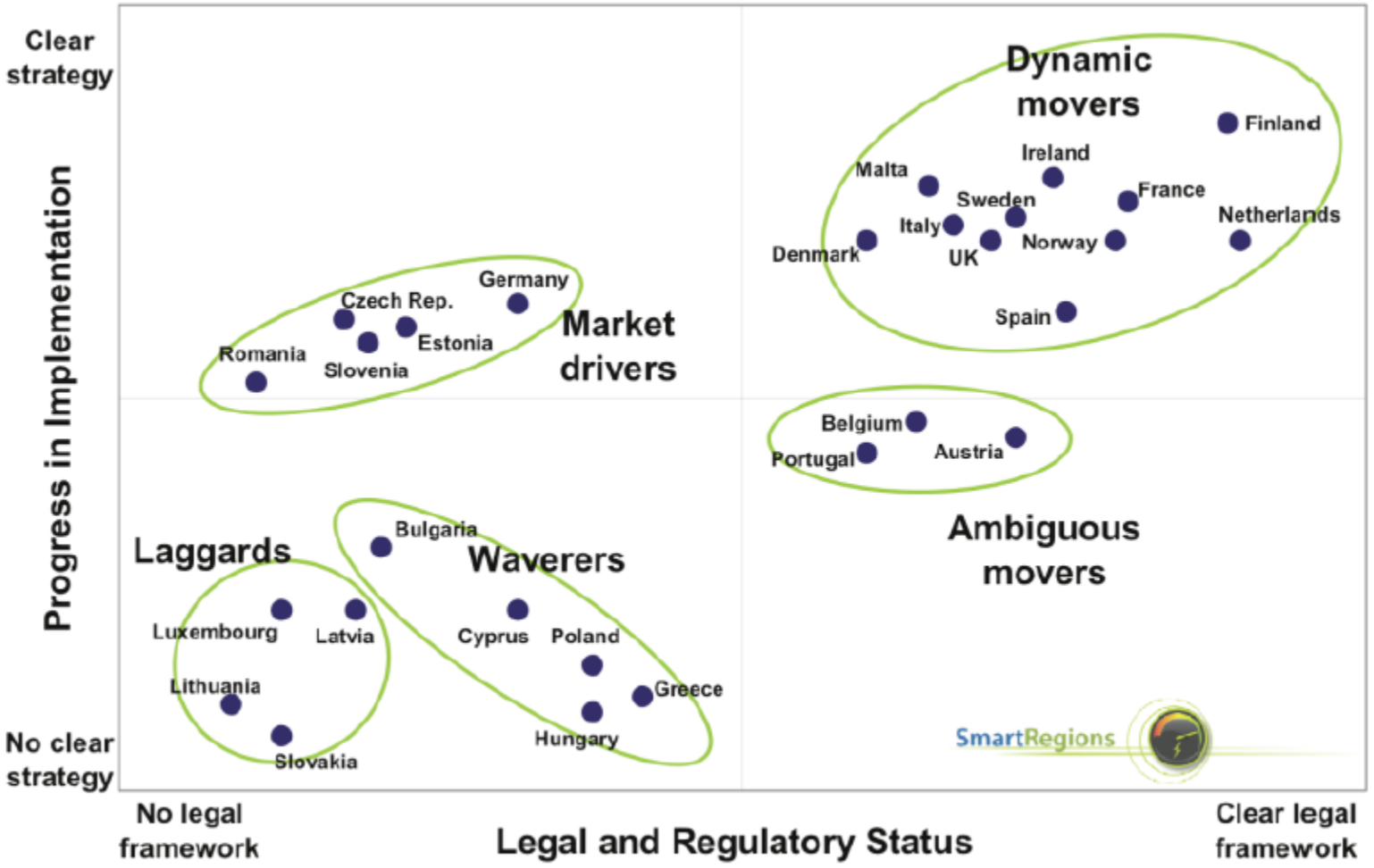
Helps integrate renewable resources like wind and solar power

Improves the grid quality (reliability)

Provides flexibility to the supplier

Adapted from “Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads”, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, VOL. 7, NO. 3, AUGUST 2011

Backup



Quelle: Austrian Energy Agency (2011), European Smart Metering Landscape Report, S. 2.

Savings Potential

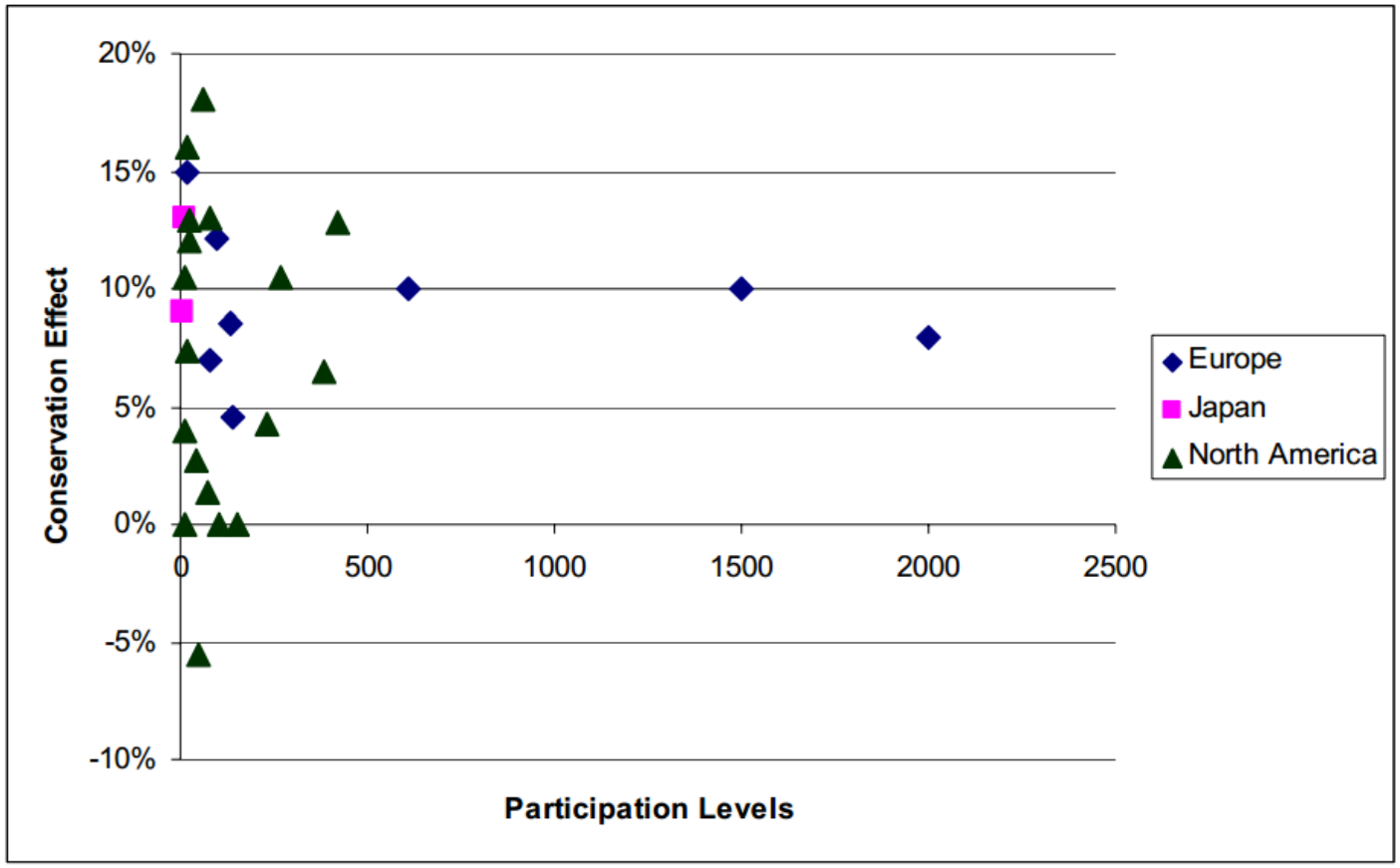
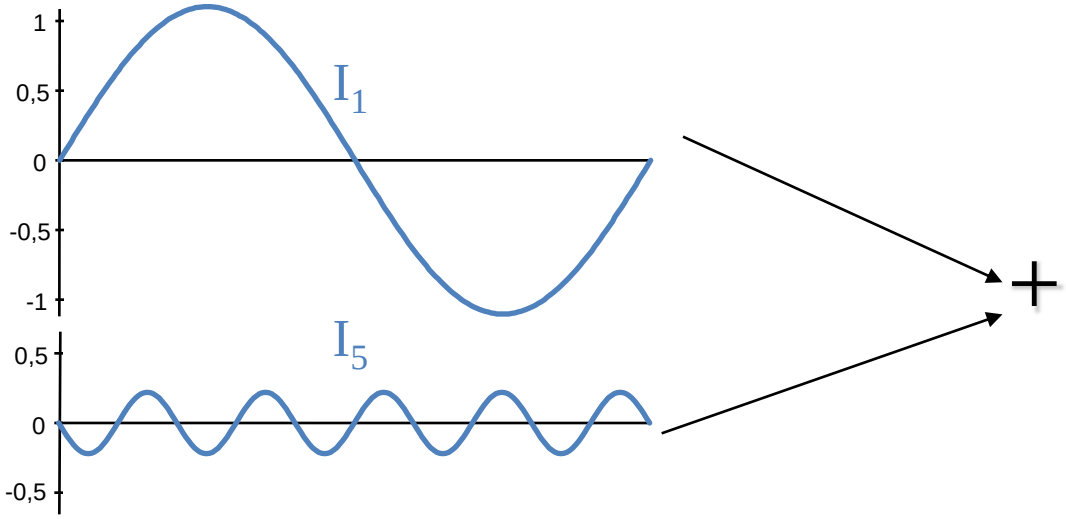
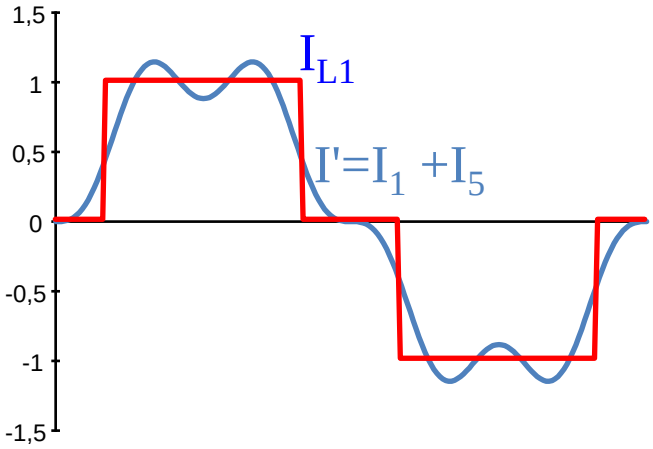


Figure 3-1
Range of study participation levels

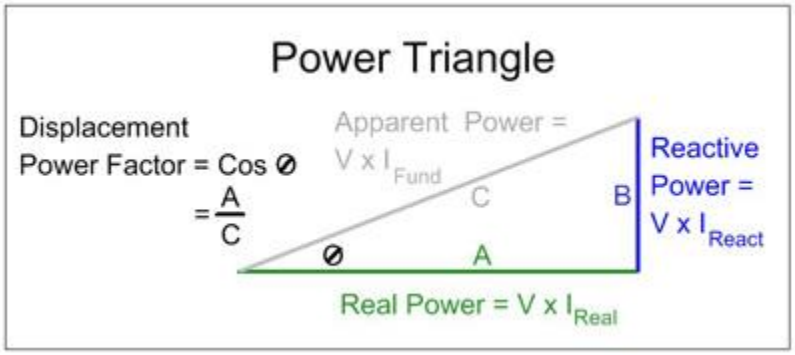
From: Neenan, B.,Robinson,J.,2009.Residential Electricity use Feedback: A research Synthesis and Economic Framework

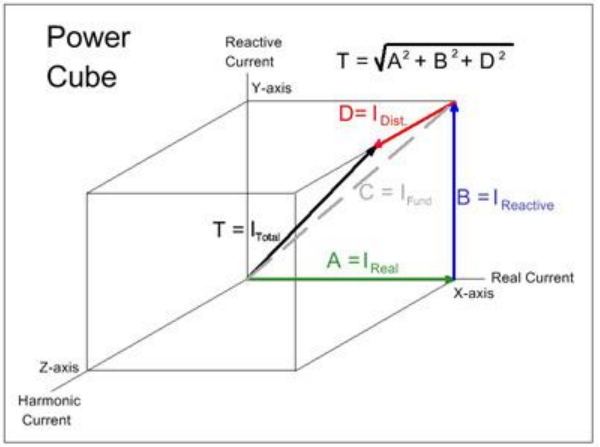
Influence of harmonics





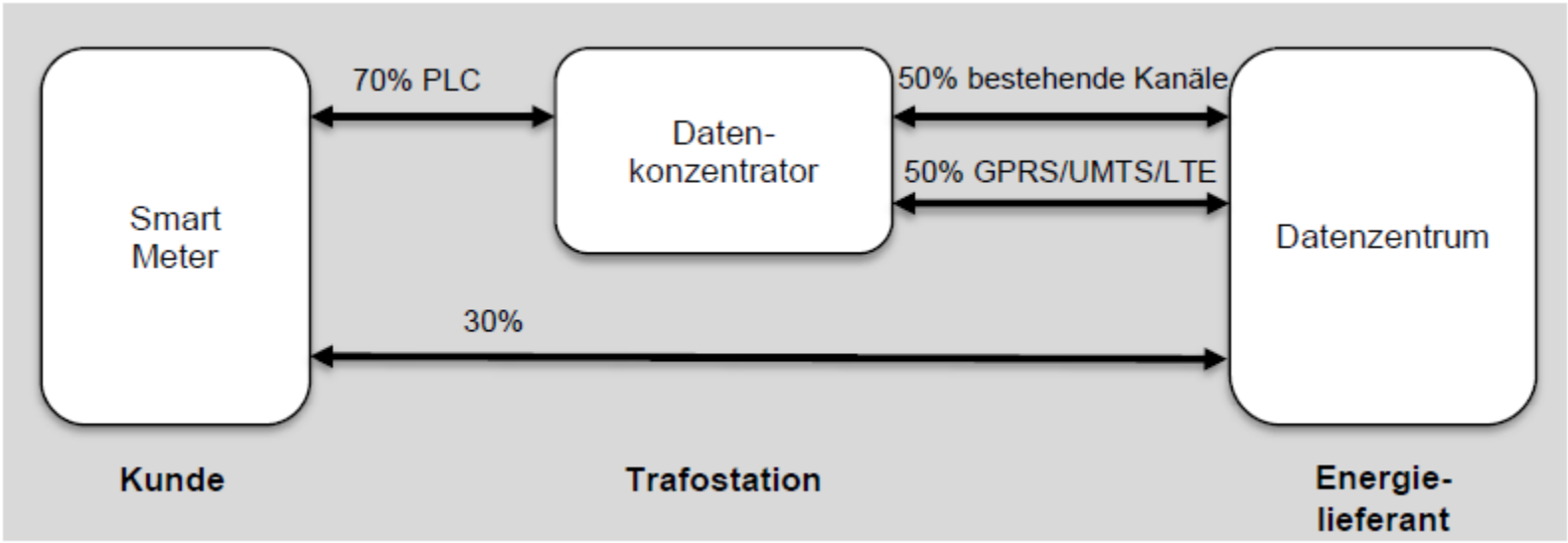
Source: Power Systems Training, ABB Limited





Source: www.home-energy-monitoring.com

Backup


Smart Meter
70% PLC
Daten-konzentrator
50% bestehende Kanäle
50% GPRS/UMTS/LTE
Datenzentrum
30%
Kunde
Trafostation
Energie-lieferant

What exists - Meter to Utility

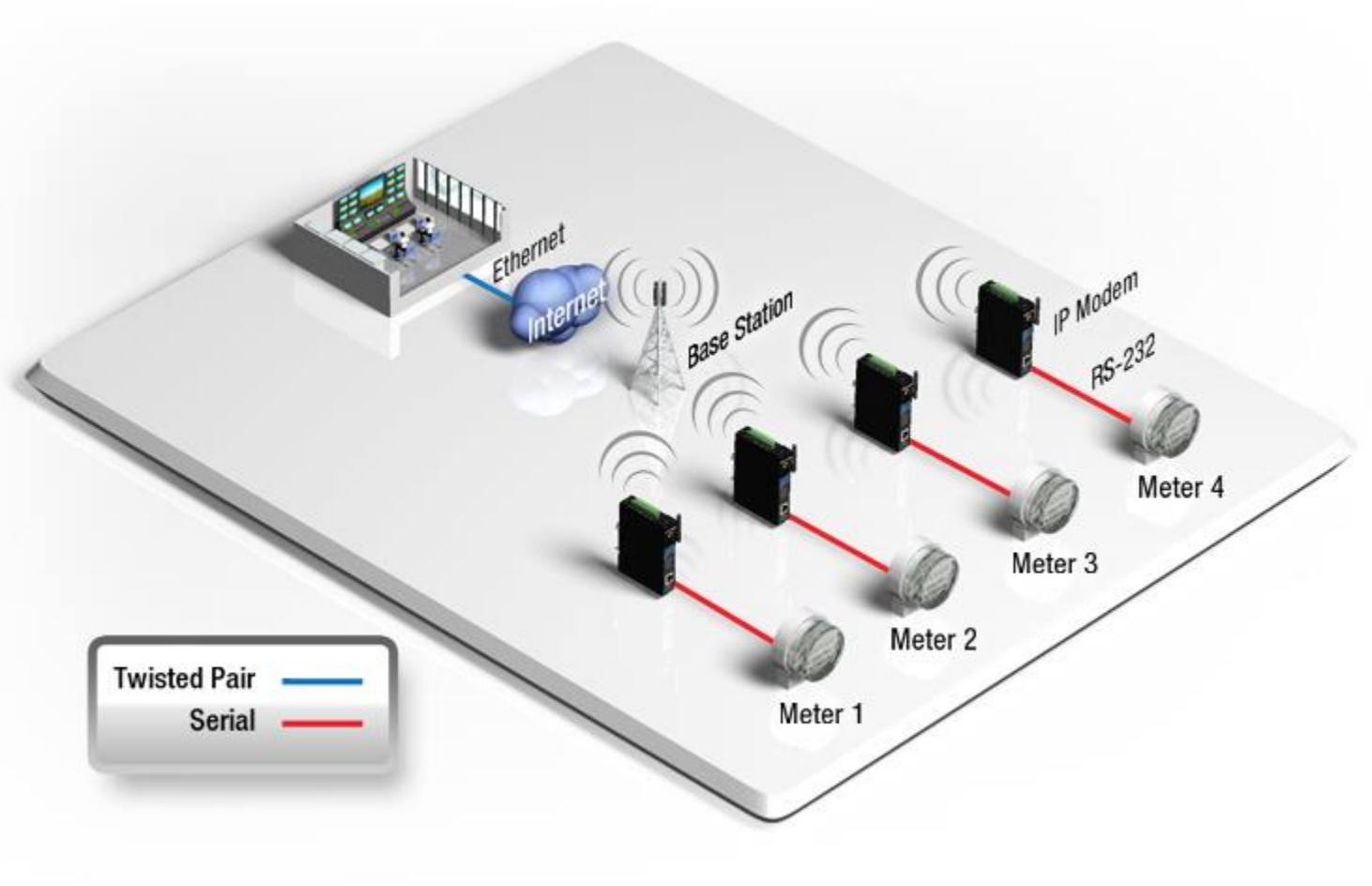
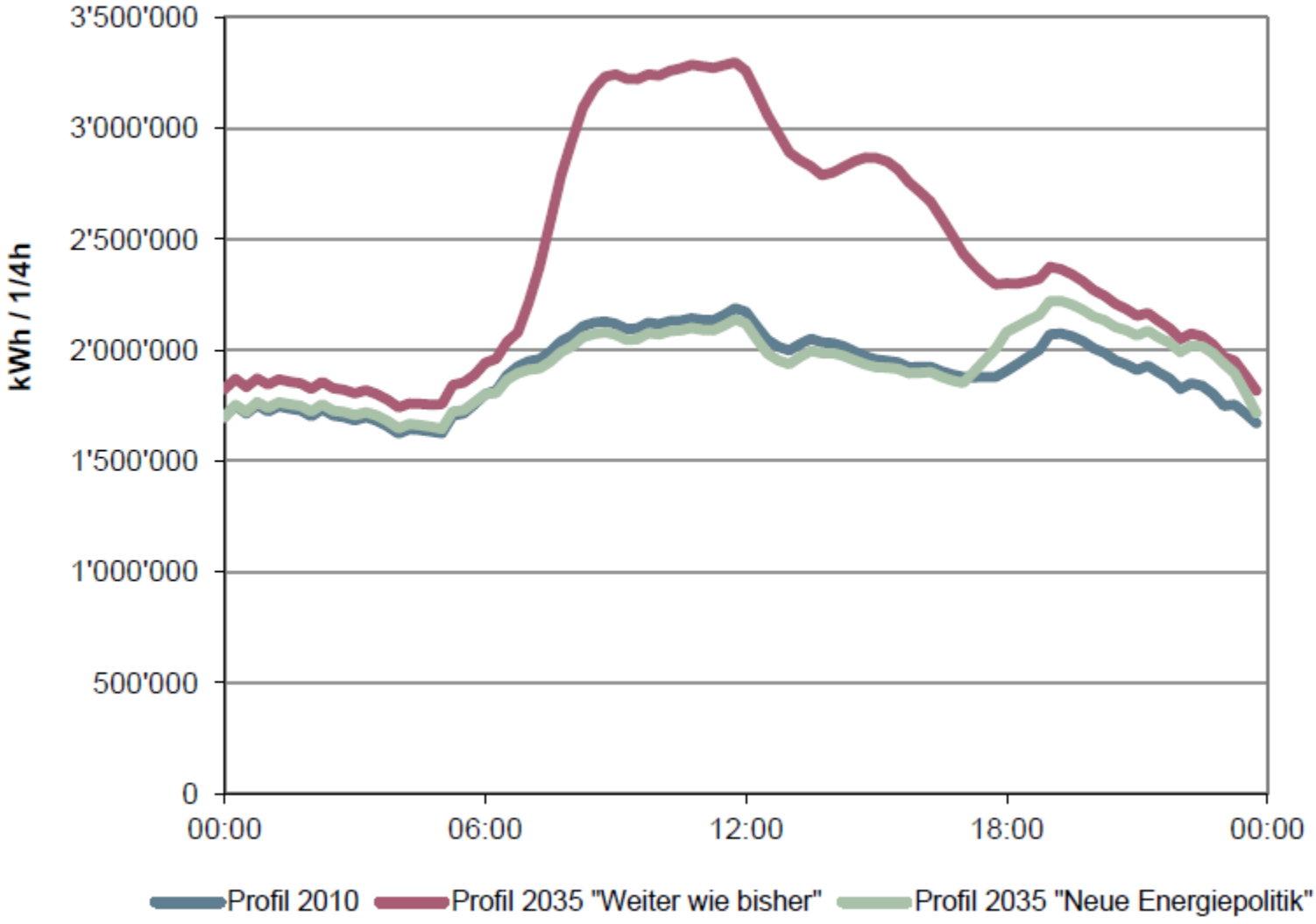
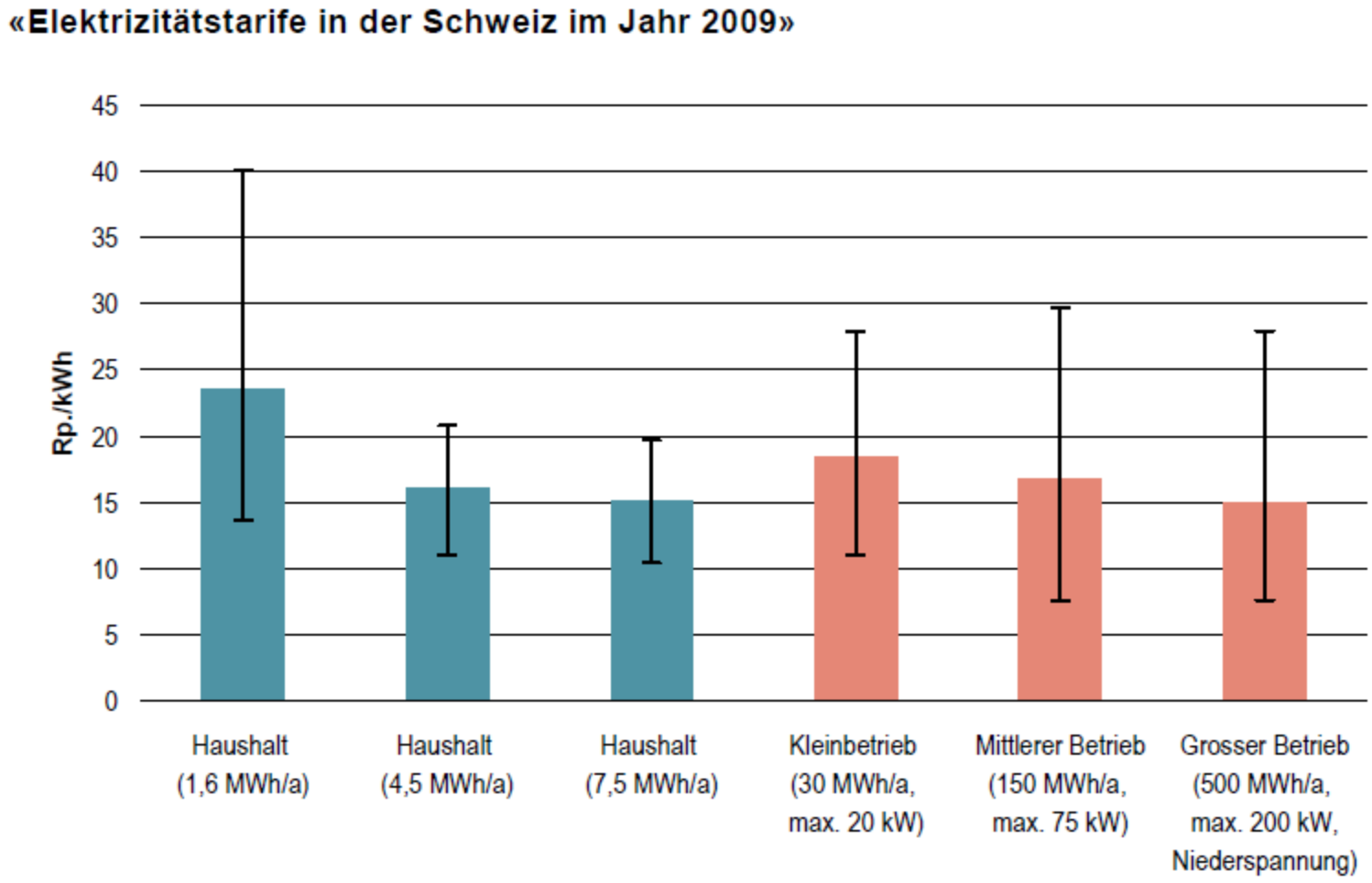


Image source: MOXA AG

Backup

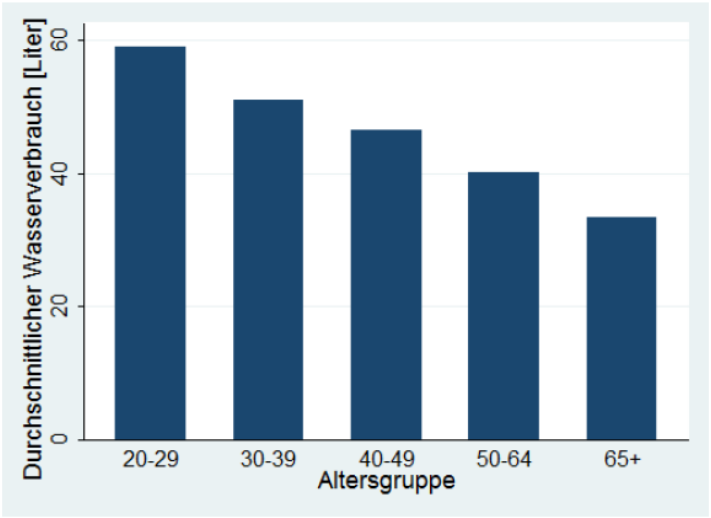

3'500'000
3'000'000
2'500'000
2'000'000
1'500'000
1'000'000
500'000
0
kWh / 1/4h
00:00
06:00
12:00
18:00
00:00
Profil 2010
Profil 2035 "Weiter wie bisher"
Profil 2035 "Neue Energiepolitik"

Backup


«Elektrizitätstarife in der Schweiz im Jahr 2009»
Rp./kWh
45
40
35
30
25
20
15
10
5
0
Haushalt (1,6 MWh/a)
Haushalt (4,5 MWh/a)
Haushalt (7,5 MWh/a)
Kleinbetrieb (30 MWh/a, max. 20 kW)
Mittlerer Betrieb (150 MWh/a, max. 75 kW)
Grosser Betrieb (500 MWh/a, max. 200 kW, Niederspannung)

Backup: Usage data

Messgrösse	Durchschnittswert
Wasserverbrauch	46 Liter
Energieverbrauch (ohne Verluste)[4]	1.6 kWh
Flussrate	11 Liter / Minute
Dauer (reine Duschzeit)	4:10 Min:Sek
Dauer Unterbrechungen (z.B. Einseifen)	34 Sekunden
Wassertemperatur	36°C



Source: Amphiro AG

Backup: Communication infrastructure for AMR

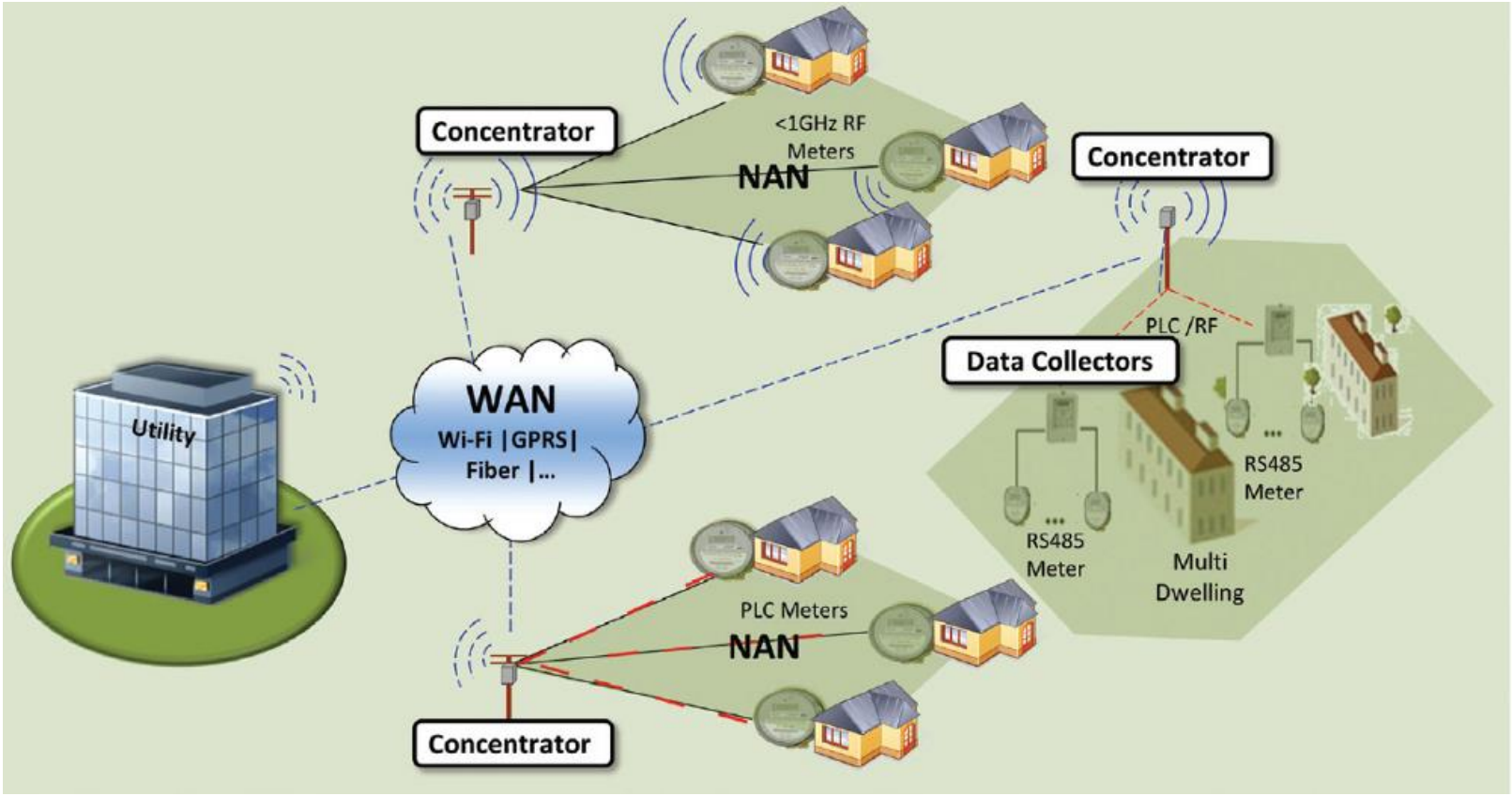
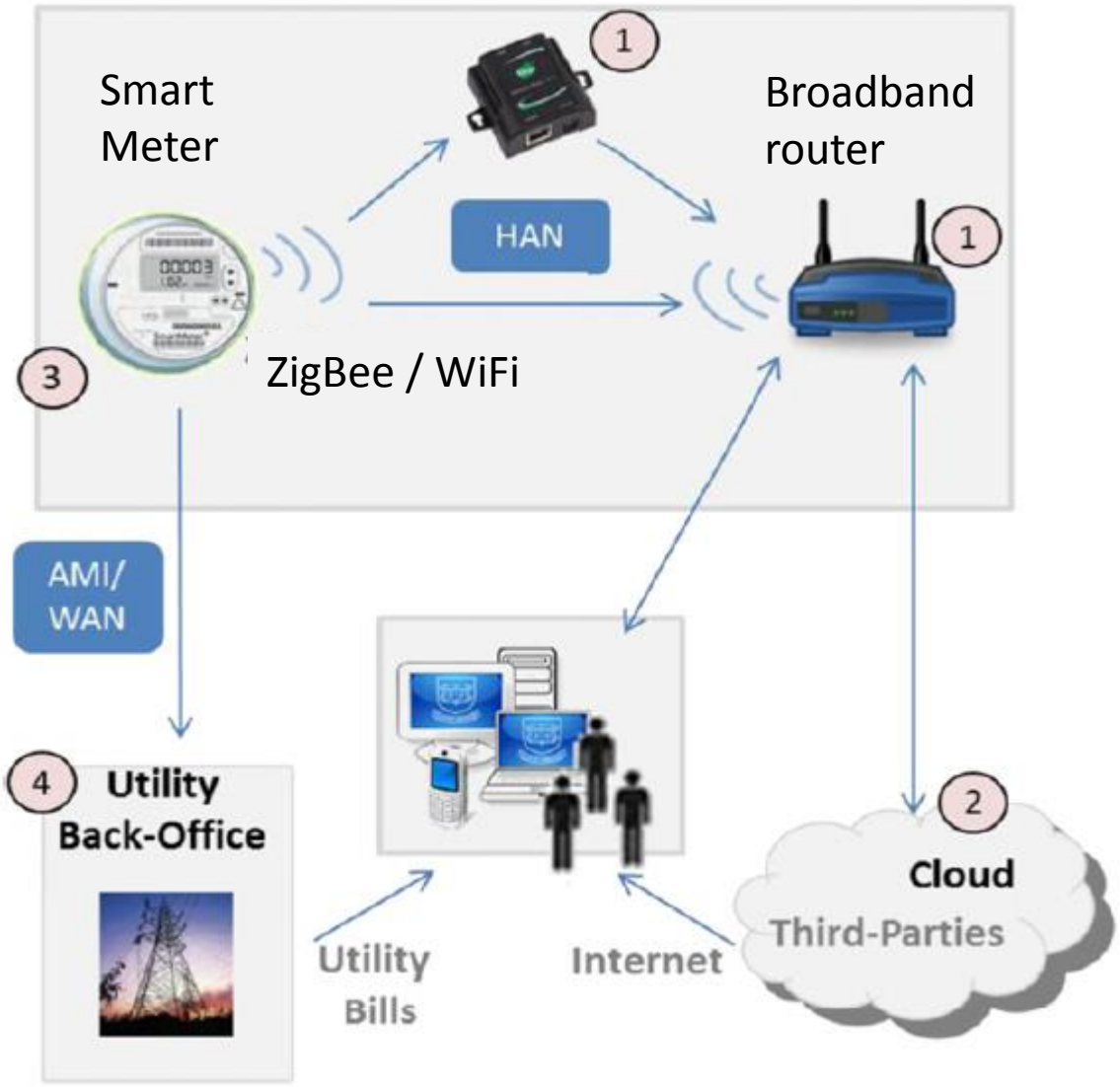


Image source: www.linuxgizmos.com

Data Integration



Meter to Utility via internet

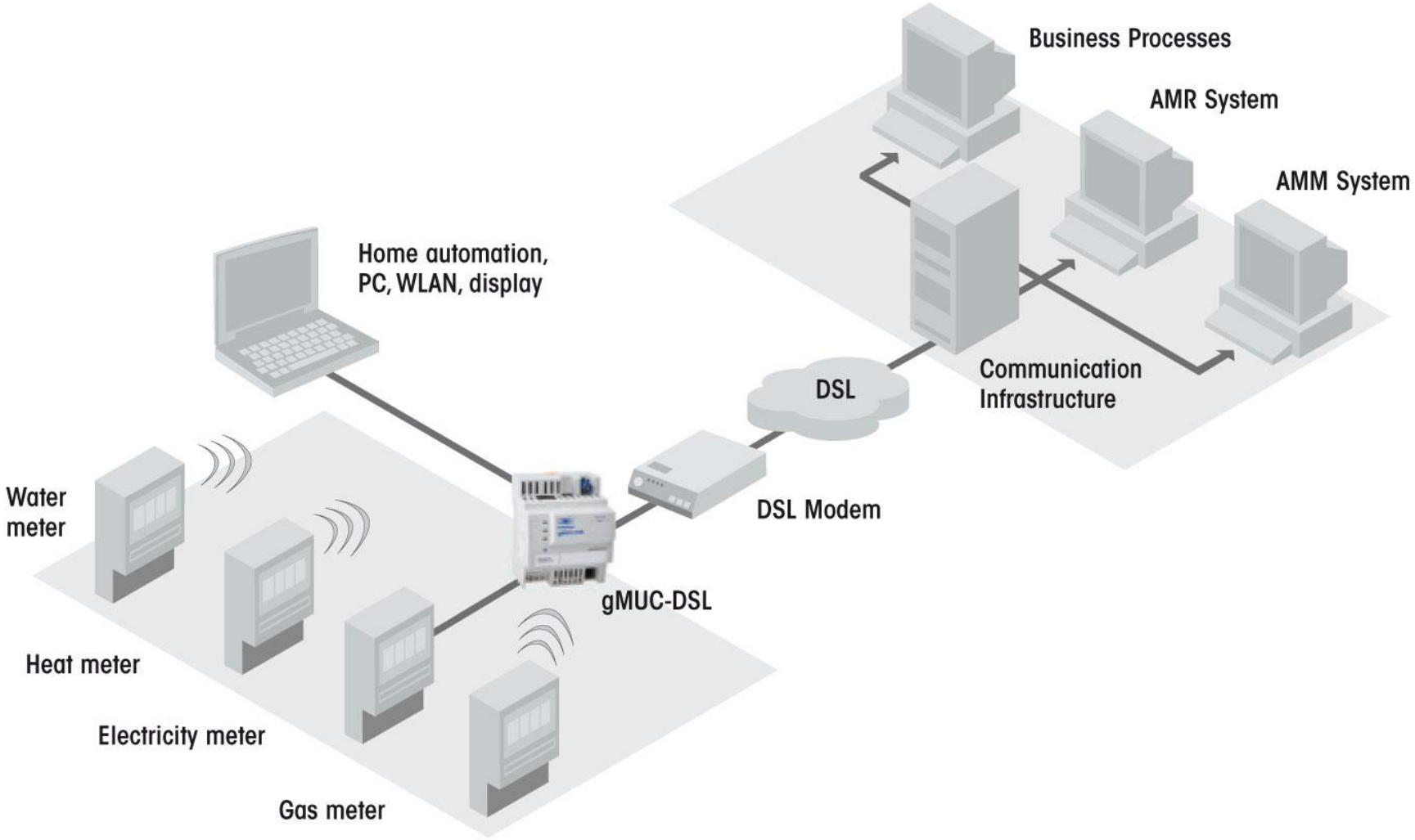
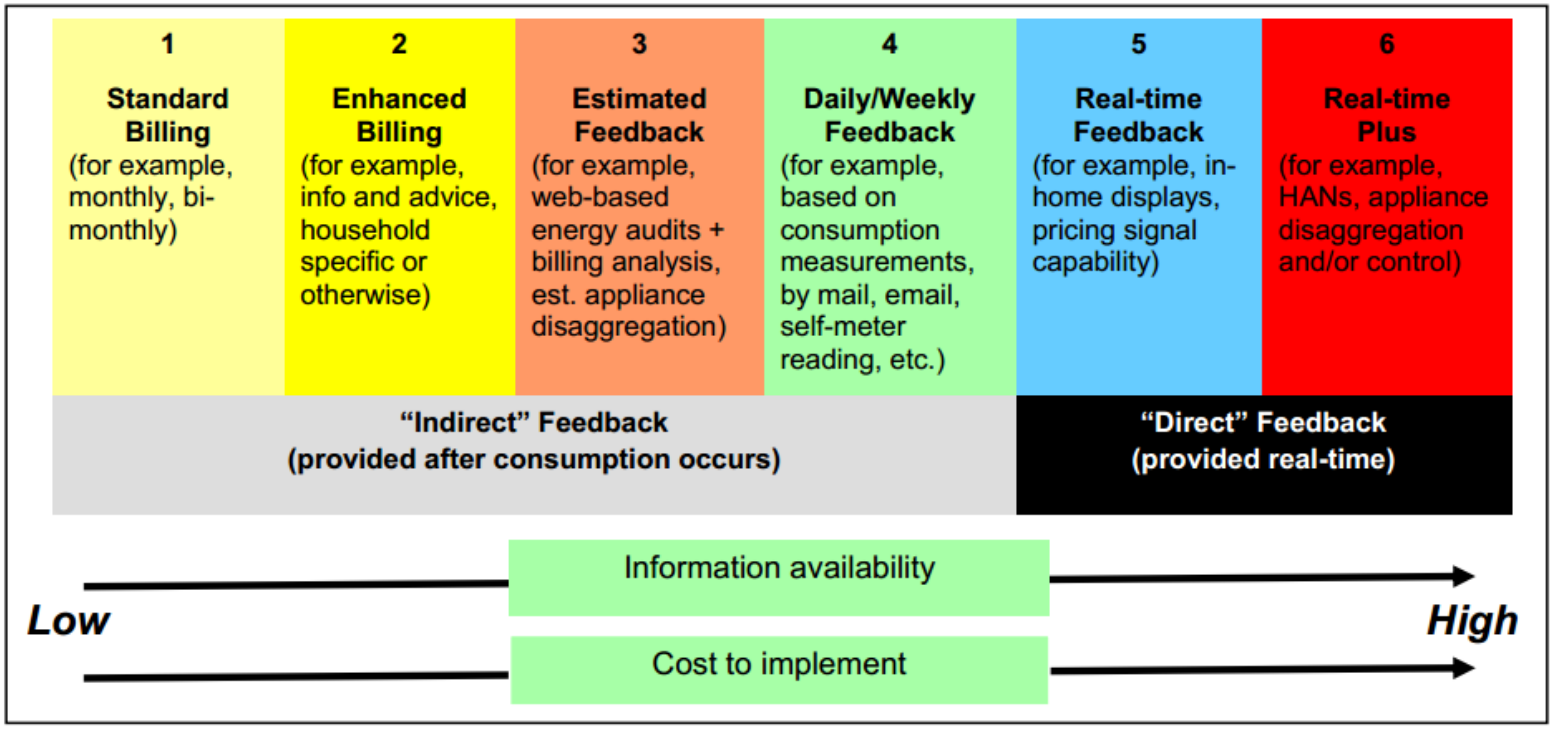


Image source: www.neuhaus.de

Energy savings – types of feedback



From: Neenan, B.,Robinson,J.,2009.Residential Electricity use Feedback: A research Synthesis and Economic Framework

Disaggregation

Monitored parameters

Current + Voltage

Real and Reactive Power

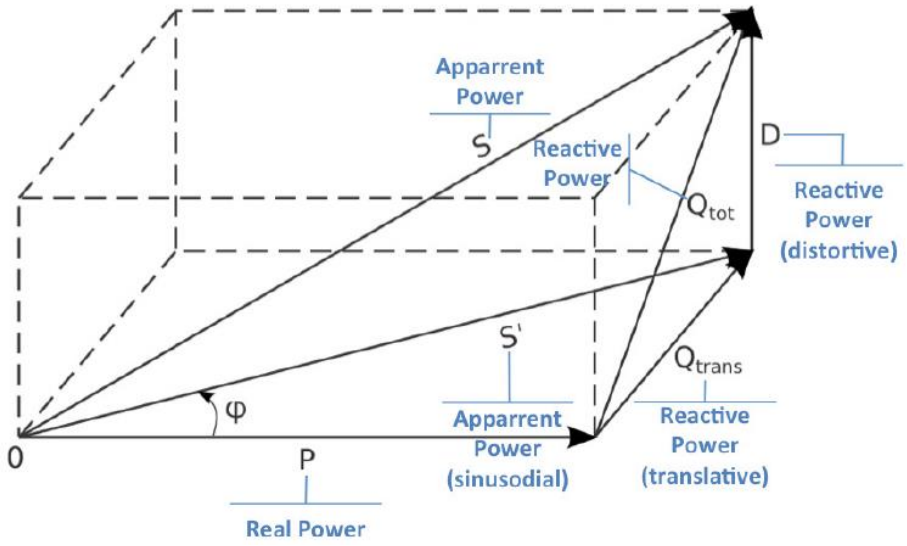
Electromagnetic emissions

Appliance states

Power line harmonics

Environmental data

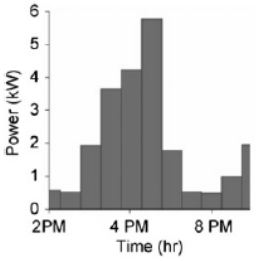
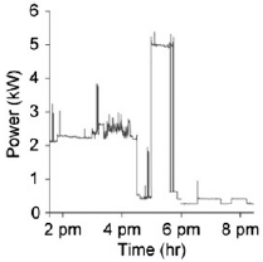
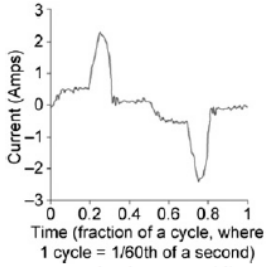
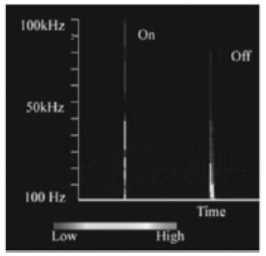
Behavioural data
(context, opportunistic sensing)



Disaggregation

Note: Improve the slide with better graphics, or move to backup!

Frequency of measurement

1 h–15 min	1 min–1 s (1 Hz)	1–60 Hz	60 Hz–2 kHz	10–40 kHz	> 1 MHz
		—	—		
Visually observable patterns; duration and time of appliance use	Steady state steps/transitions of power	Steady state steps/transitions of power	Current and voltage, providing low order harmonics	Current and voltage, providing medium order harmonics to identify type of electrical circuitry in appliance	Current and voltage, providing very high order harmonics to identify both transients & the background noise of appliances
Differentiates ~3 general categories: loads that correlate with outdoor temperature, loads that are continuous, and loads that are time-dependent	Top < 10 appliance types: refrigerator, ACs, heaters, pool pump, washers, dryers etc.	10–20 appliance types	Not known, see text for more details	20–40 appliance types: toasters, computers, etc. along with larger loads identified at lower frequencies	40–100 specific appliances: e.g., differentiates between 2 lights; requires separate power consumption data stream

Disaggregation

Factors influencing the algorithm

Frequency of measurement

Monitored parameters

Measurement resolution

Performance

Number of appliances detected

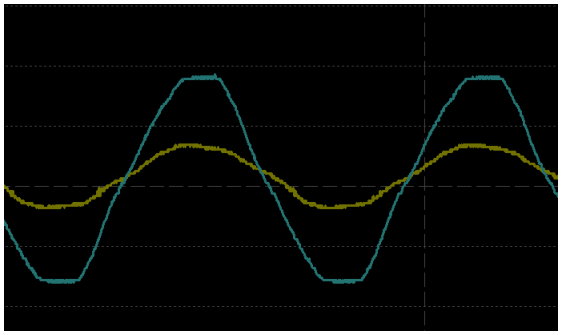
Fraction of power explained

Accuracy of power measured

Image source : Hart, G., 1992. Nonintrusive appliance load monitoring. Proceedings of the IEEE 80 (12), 1870–1891

Disaggregation

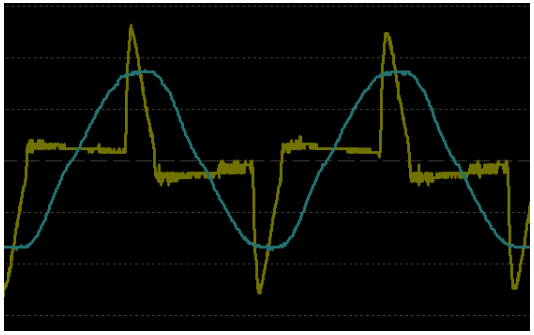
Measurement frequency



“Pure” resistive load

Filament bulb

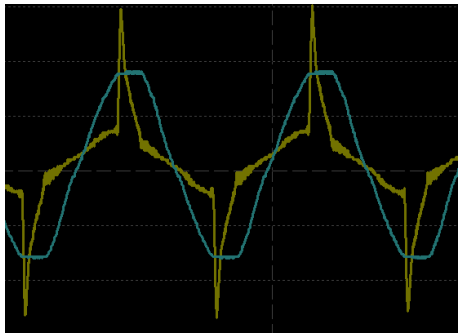
+



Load with harmonics

Laptop Charger

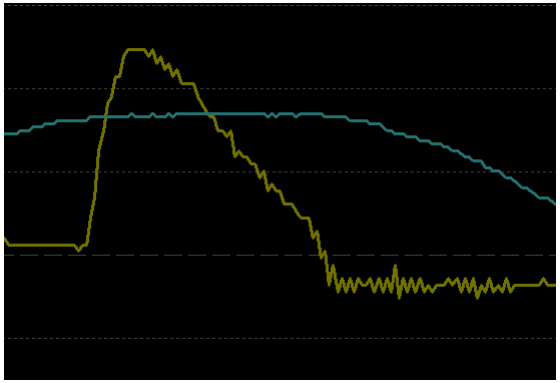
=



Aggregate waveform

Both together

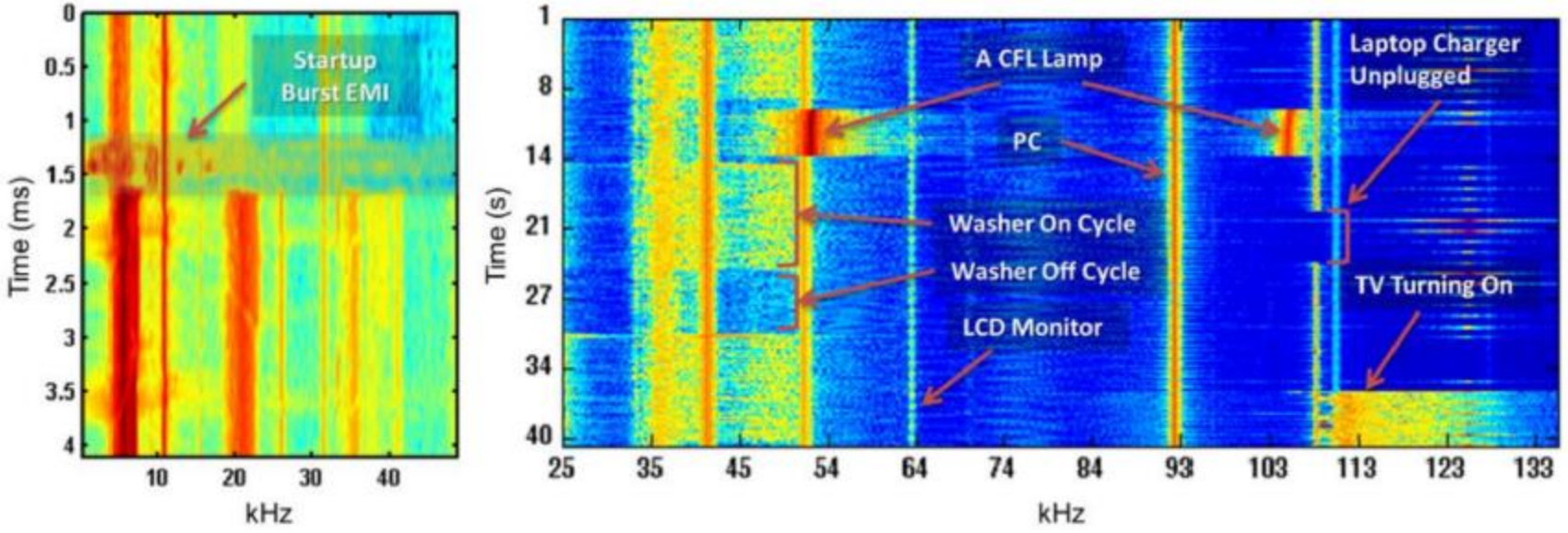
If we measure less than the fundamental supply frequency, then we cannot distinguish appliances.
Higher the better! (but more expensive!)



Example: Measuring at 1 MHz we can even distinguish between two laptop chargers!

Disaggregation

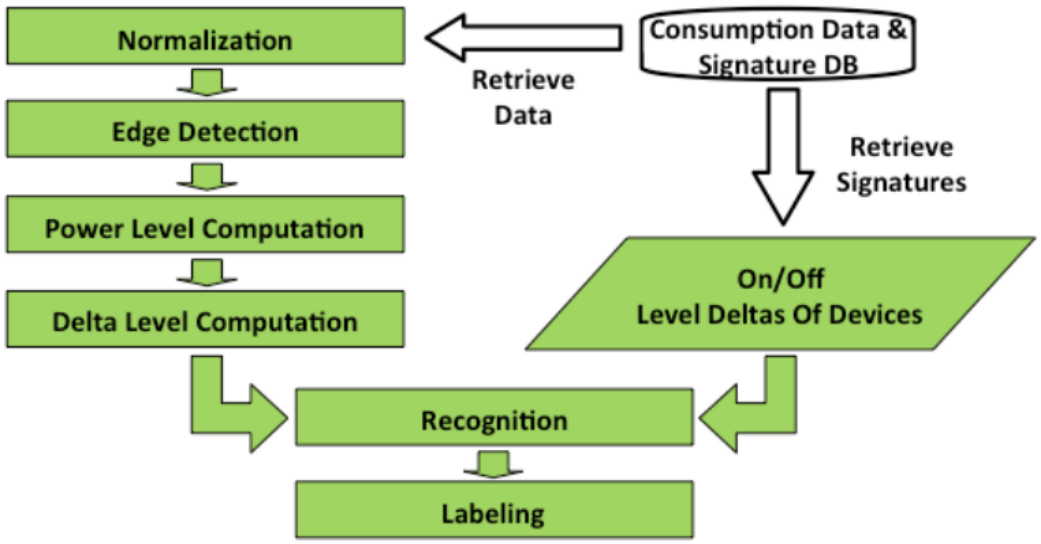
Frequency of measurement – spectral analysis



Almost prohibitive cost of hardware, but high resolution data – can even distinguish between two CFL lamp of same type!

Disaggregation

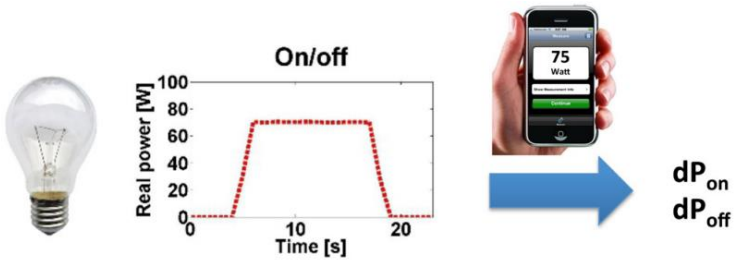
Algorithms



- **Recognizing state changes (clustering) and then matching it to a library content**
- Machine learing, sparse coding
- Neural algorithm
- ...

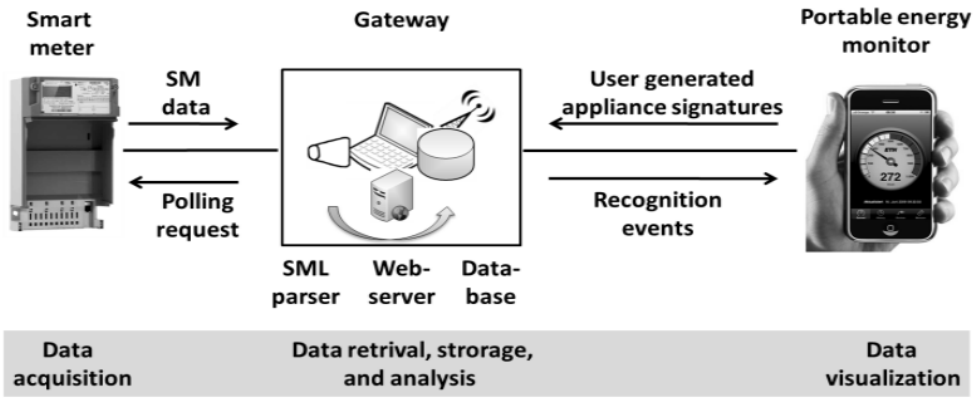
Disaggregation

Signature Training

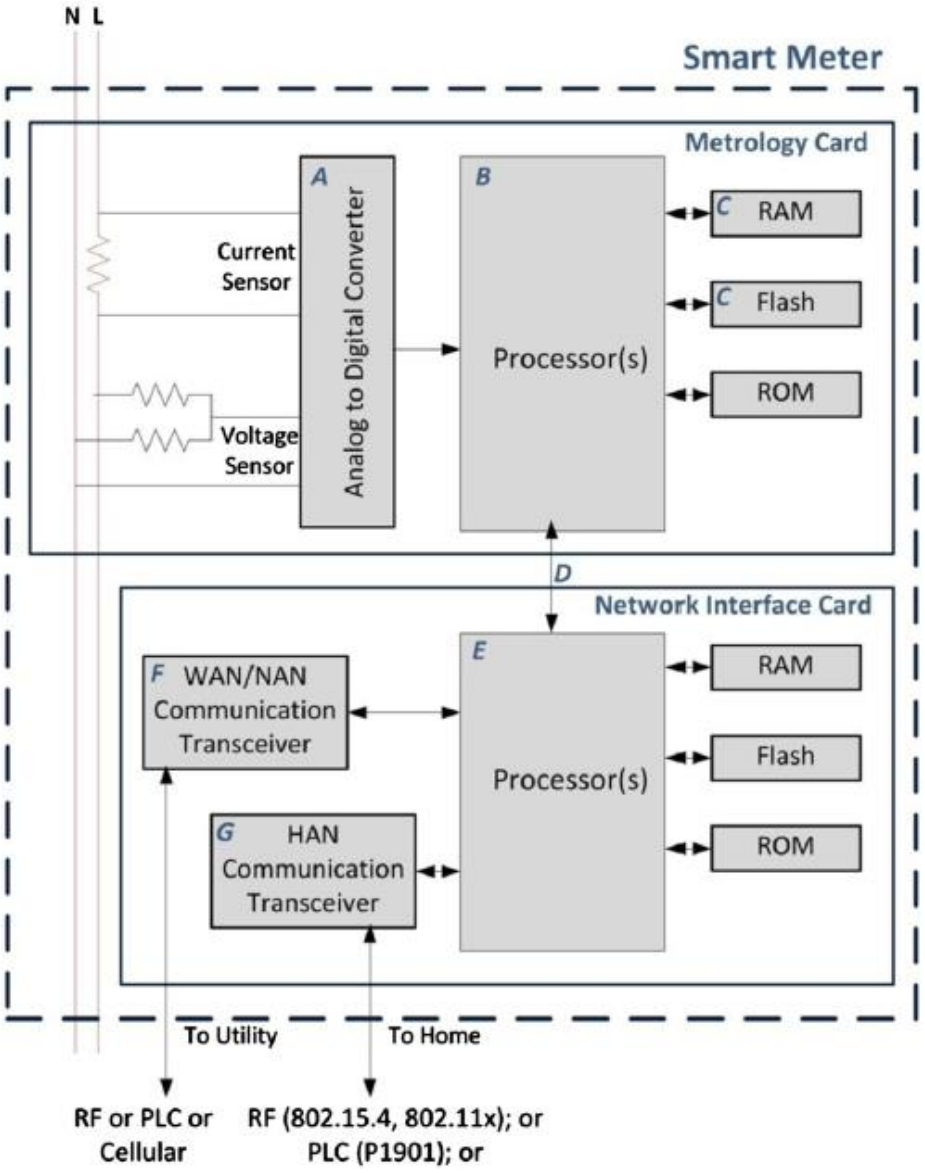


User-friendly signature acquisition process with the help of the measurement feature of the user interface.

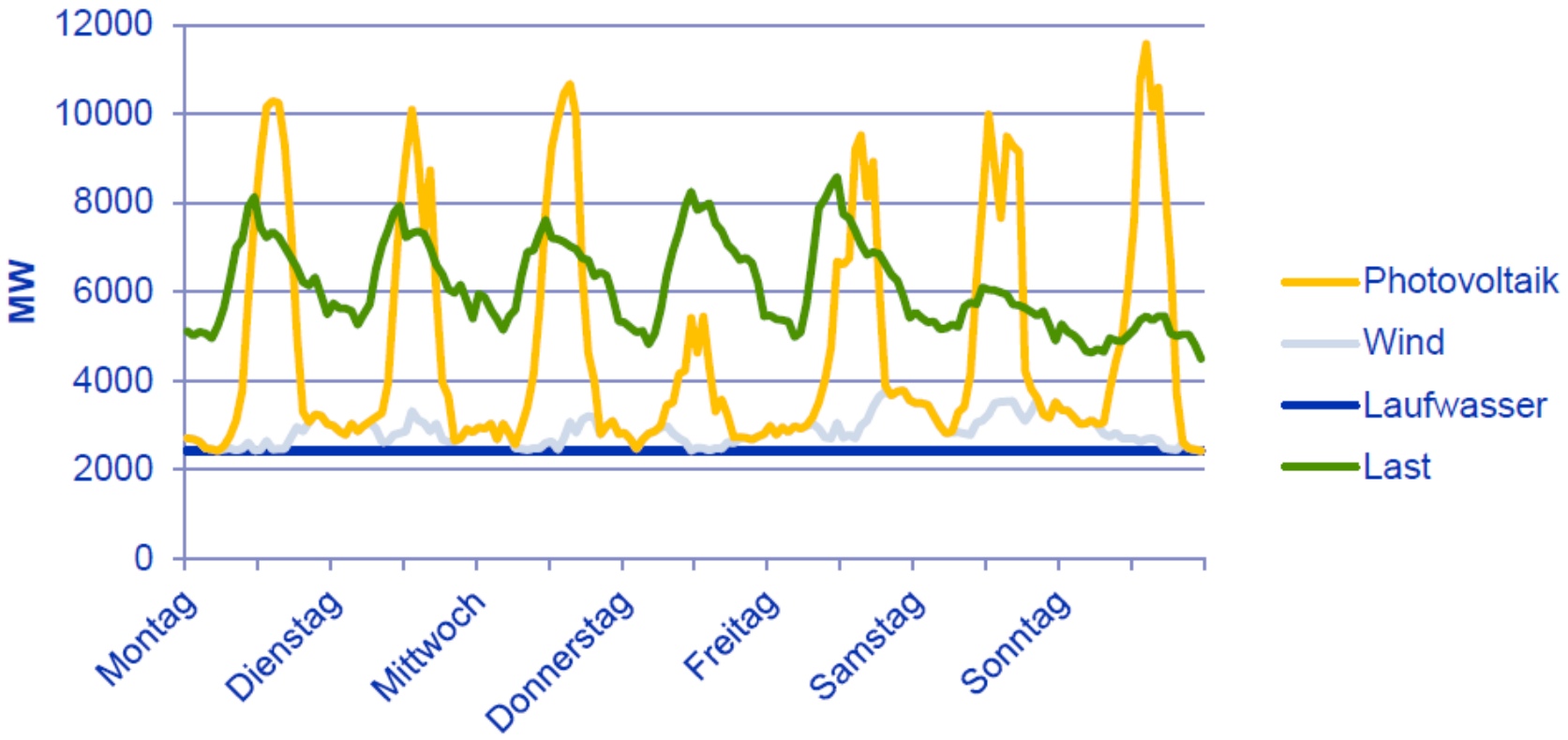
User process to measure the power consumption of an individual appliance (e.g., an office flood light).



SmartMeter


N L
Smart Meter
Metrology Card
A
Analog to Digital Converter
Current Sensor
Voltage Sensor
B
Processor(s)
C RAM
C Flash
ROM
D
Network Interface Card
E
Processor(s)
RAM
Flash
ROM
F WAN/NAN Communication Transceiver
G HAN Communication Transceiver
To Utility
To Home
RF or PLC or Cellular
RF (802.15.4, 802.11x); or PLC (P1901); or

Backup: Energy 2050



Source : Energiespeicher für die Schweiz Endbericht, KEMA 2013

Direct Load Control (DLC) + user acceptance *

2008 update to California's Building Standard (Title 24) required new homes and retrofitted homes to install programmable communicating thermostats (PCTs), which receive wireless signals allowing utilities to control temperature during grid emergencies

Public outcry!

January 4, 2008

Who Will Control Your Thermostat?

By Joseph Somsel

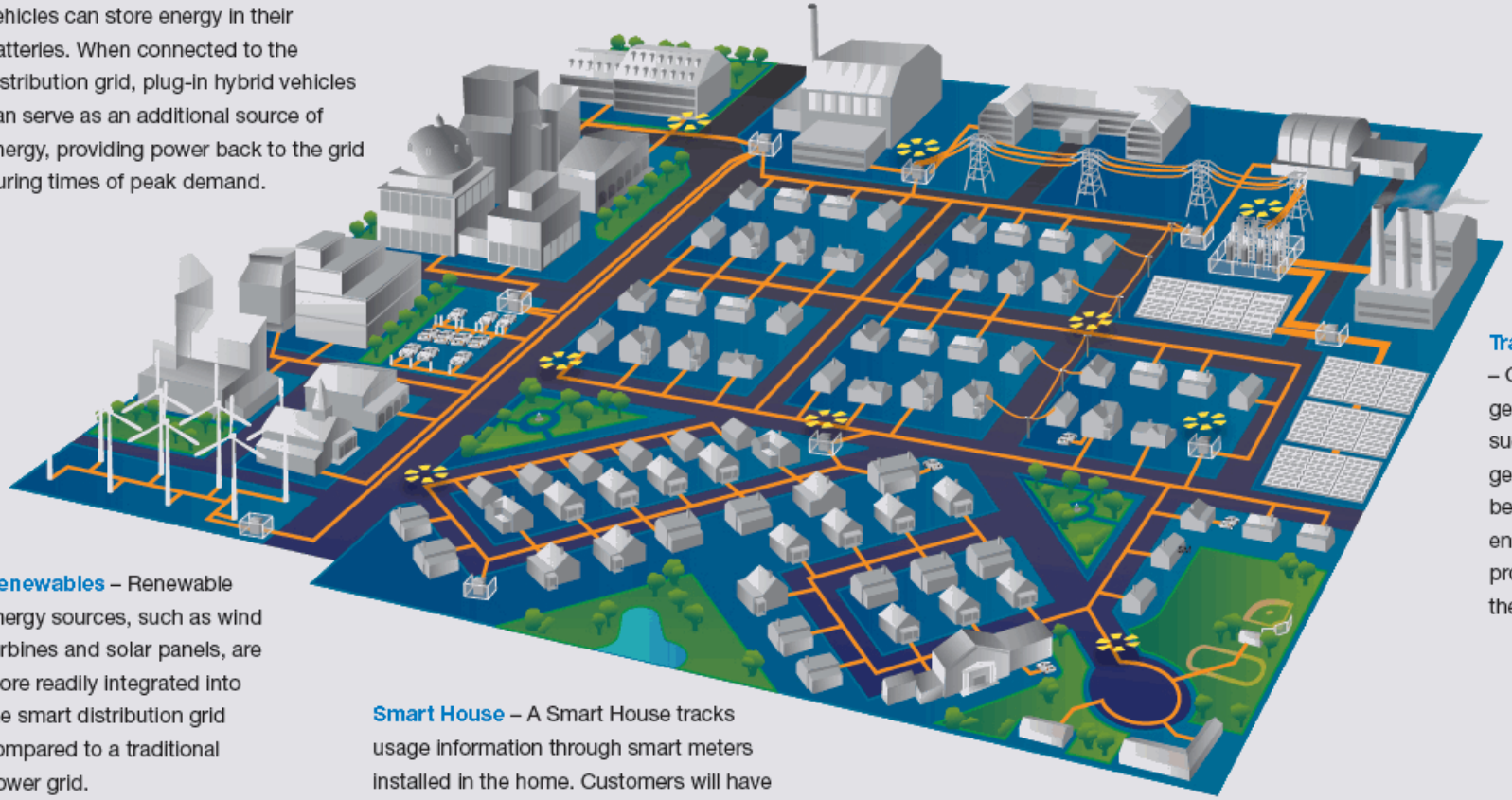
*"There is nothing wrong with your thermostat. Do not attempt to adjust the temperature. We are controlling your power consumption. If we wish to make it hotter, we will turn off your air conditioner. If we wish to make it cooler, we will turn off your heater. For the next millennium, sit quietly and we will control your home temperature. We repeat, there is nothing wrong with your thermostat. You are about to participate in a great adventure. You are about to experience the awe and mystery which reaches from the inner mind to... SACRAMENTO!"**

[http://www.americanthinker.com/2008/01/who_will_control_your_thermost.html]

*Source: Mathieu, ETH Zürich «Demand Response Today» CDC Workshop 2013

Sensors – Advanced communication equipment on the grid, including sensors, enable utilities to monitor, identify and quickly correct problems. Increased reliability of power is the result.

Plug-In Hybrid Vehicles – Plug-in hybrid vehicles can store energy in their batteries. When connected to the distribution grid, plug-in hybrid vehicles can serve as an additional source of energy, providing power back to the grid during times of peak demand.



Traditional Generation – Over time, traditional generation assets such as coal-fired generation plants will be offset by renewable energy sources in providing energy to the distribution grid.

Renewables – Renewable energy sources, such as wind turbines and solar panels, are more readily integrated into the smart distribution grid compared to a traditional power grid.

Smart House – A Smart House tracks usage information through smart meters installed in the home. Customers will have a variety of options through which they can interface with to learn about the most cost-efficient energy usage patterns. Increased information empowers consumers to reduce their energy use.

Source: Nationalgrid.com

The next 40 minutes...