Vienna University of Technology
Faculty of Informatics
Institute of Software Technology and Interactive Systems
Favoritenstr. 9-11/188
1040 Vienna, Austria

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Approaches for Monitoring and Reduction of Energy Consumption in the Home

Tobias Hochwallner
Lukas Lang

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Supervised by Alexander Schatten

Abstract

By now, energy consumption in the home or even for single devices has not been monitored widely, except for billing and accounting reasons. Consumers are not able to track individual load profiles, therefore positive or negative trends in consumption were not noticed immediately. This work is based on the importance of direct feedback and its savings potential in terms of energy consumption: *If you can't measure it, you can't improve it.* We compare various monitoring approaches such as metering on device level, smart meters and non intrusive load monitoring of electrical devices. Furthermore, the discuss downsides like effectiveness, acceptance and privacy issues.

1 Introduction

In a world of highly developed countries and emerging economics, energy supply plays a major role. In a modern household, hardly any device runs without electricity. Load profiles are the overlay of a household's energy demand. Consumers are not able to keep track of individual energy consumption. The basic idea of this work is: *If you can't measure it, you can't improve it.* We give an overview about energy production, individual energy consumption, savings potential and discuss various approaches for monitoring energy consumption at different levels and their drawbacks e.g. effectiveness, acceptance and privacy issues. Furthermore, we explain why reducing peaks in energy consumption is important and how to effectively gain awareness of consumers by giving instant feedback.

2 Current Situation

Basically, it is not a big secret that when plugging in the jack of a device, the energy driving it must be produced in some way and transferred to the device. Energy on its way to the consumer is transferred from an energy emitting source to the customer. Electrical energy (electricity) for example is produced in power plants, mostly by burning fossil fuels [10], conducted via a provider's power grid and consumed by a customer[1].

The accumulate consumption of energy will be reflected by the monthly bill. For the time of consumption there is no other indicator for the amount of energy spent than the device's power usage indicated by the model plate[2]. It is not reasonable to customers to keep track of their individual energy consumption. Hence, assisting monitoring systems, discussed in Section 6 are needed to give instant feedback by displaying actual, historic energy usage and monthly costs. One the one hand, the fundamental goal is to gain awareness of energy consumption and eliminate unnecessary load by making customer changing their habits and on the other hand, remove peaks in global consumption and displace it so that production surplus and probably cheaper supply is being used.

At first glance, the consumer's direct incentive to decrease personal energy consumption is pretty obvious: It will lead to a lower bill at the end of the month. On closer examination, a change in overall consumption will effect energy production. On a global level, it is inevitable to establish new energy policies to reduce dependency from fossil fuels and to reduce *greenhouse gas (GHG)* emissions[3] to lower consequences of climate change and global warming [22]. This leads to the basic question: *At what level can*

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[1] We are aware of the fact that in a closed system, energy can neither be "produced" nor "destroyed", but converted from one kind to another.

[2] Model plates usually state a device's *nominal power*. Depending on the type this is the *consumed* or the *yielded* power.

[3] The primary greenhouse gases in the earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), nitrous-oxide (N_2O), methane (CH_4) and ozone (O_3) [16].

improvement be achieved? First, it has to be clear that changes in energy policies will need a certain time to be implemented and result in lower energy consumption and therefore in reduced GHG emissions. In the following sections, we discuss the complex connections of energy production and consumption and proceed with discussion of various monitoring approaches.

3 Energy Production

In previous sections we used the terms *energy* and *power* intuitively, but did not define measurements from a physical perspective. For the sake of completeness we will make up missing definitions and proceed then with discussion of energy production.

We think that the definition used by MacKay [13] achieves enough clarification for the scope of our work: We will also use the unit *kilowatt-hour (kWh)* for phrasing amounts of energy because it is the most acceptable dimension[4]. Furthermore, MacKay defines power as follows:

> "Power is the rate at which something uses energy." [13]

For power we will use the unit *kilowatt-hour per day (kWh/d)*[5]. Consequentially, a widespread comparison to driving a car can be drawn: Power represents the speed of a car (measured by the speedometer), energy the distance a car would have traveled by a certain time (measured by the odometer) [24].

3.1 Loads and Power Plants

When managing a sophisticated energy supply, the balance between demand and supply side must be guaranteed. Power plants should supply the exact amount of energy demanded, otherwise exceeding energy and money will be wasted unnecessarily. To establish balance, the following requirements must be met:

- prediction of energy demand
- supply of unforeseen energy demand
- dealing with unexpected failure of power plants, the grid or consumers

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[4] The prefix k expresses the one thousand-fold of the given value. For more standard prefixes have a look at *International System of Units (SI)* [3]

[5] Alert readers may have noticed that time is eliminated and the result is kW, which exactly matches the yield of e.g. an electrical device.

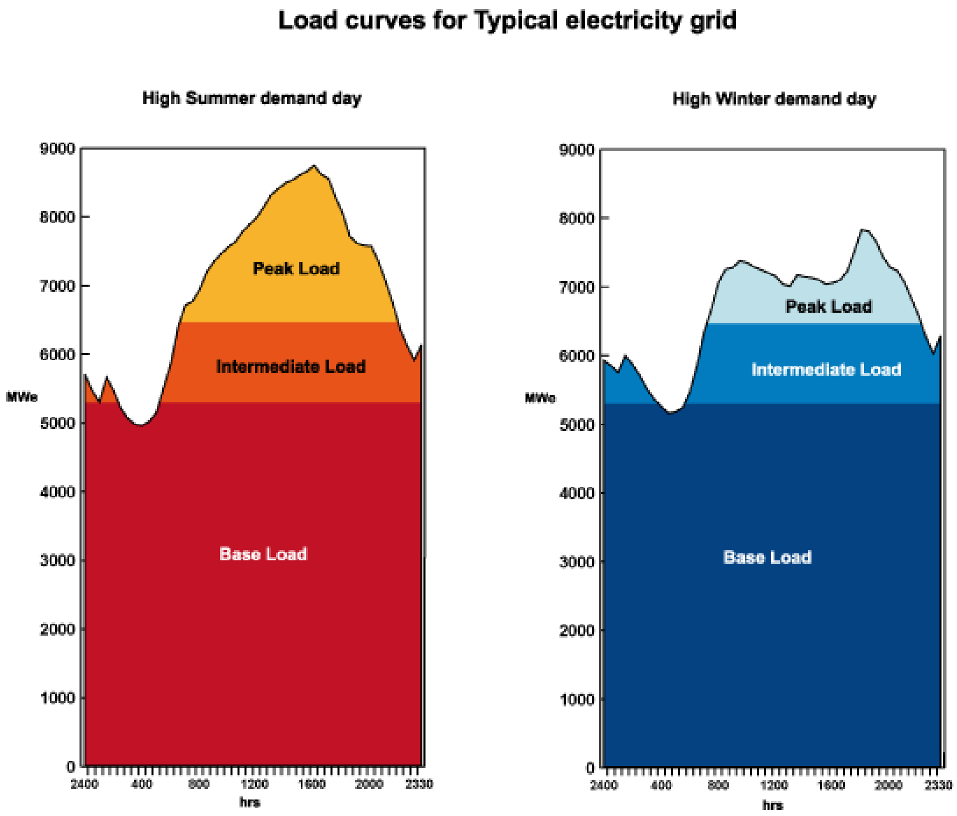

Figure 1: Load curves for typical electricity grid[6]

The overall energy demand is the accumulated amount of energy of all customers being connected to a power grid. Figure 1 shows typical load curves for winter and summer, which are characterized by heavy variations in loads. The overall daily load can be categorized as three types: The *base load* is the minimum daily demand and mostly produced by cheap and continuously running power plants such as thermal (e.g. coal-fired), nuclear and hydroelectric power plants. *Mid-load* exceeds the base load and correlates to a population's daily routine and typical occurs in forenoon and in the evening. Typical mid-load power plants are stone coal fired. *Peak load* appears when energy demand is above average (e.g. when a considerable part of a population returns back from work or starts cooking) or unforeseen incidents like changes in weather arise. Peaking loads are covered by peak power plants such as (pumped storage) hydroelectric power plants or gas turbines. The unsteady appearance of loads does not imply that energy demand is not predictable. Management of energy supply relies on statistic analysis of energy consumption to schedule various types of power plants to meet energy demand.

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[6] `http://www.world-nuclear.org/uploadedImages/org/info/victorialoadcurve.gif`

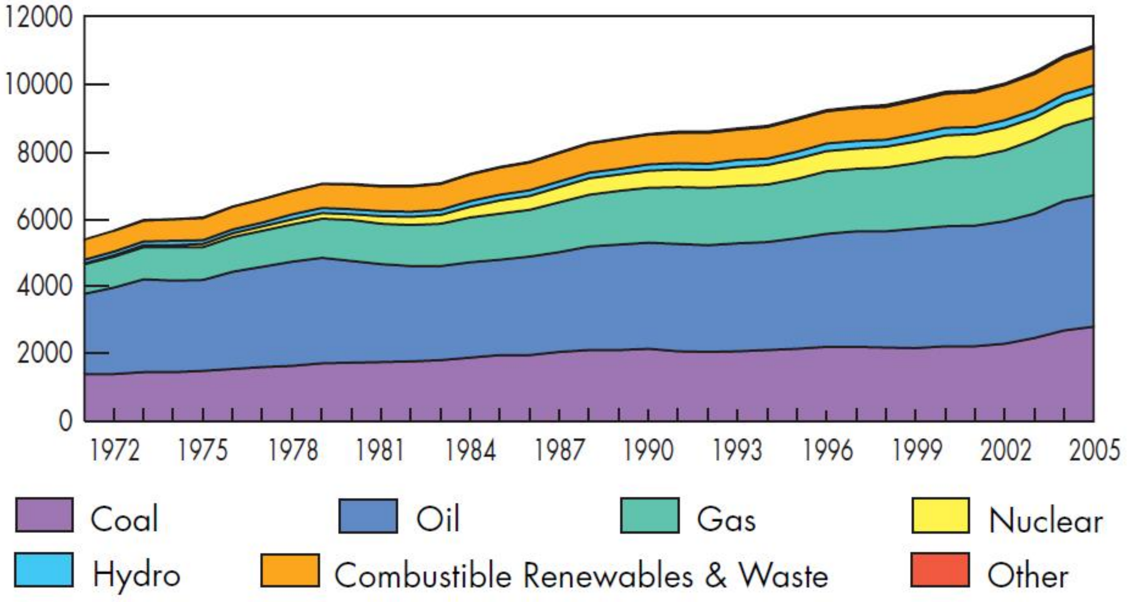

Figure 2: World Total Primary Energy Supply by Fuel (Mtoe) [10]

3.2 Scenarios for Future Development of Energy Consumption

In the previous section, we discussed energy demand and various types of power plants. To keep product costs low, global economy is seeking for cheap energy. To lower scarcity on energy market, new power plants are only built when electrical energy is expensive [6]. As the global demand for energy, disclosed as *Total Primary Energy Supply (TPES)*[7] has increased steadily over the last thirty years (see Figure 2), the *International Energy Agency (IAE)* has defined three scenarios for future trends of the TPES by the year 2030 [11]. By 2005, the vast majority of energy supply is generated out of fossil sources (see Figure 3).

3.2.1 Reference Scenario

The *Reference Scenario* is based on the assumption that growth rate of world economics and demographic development will stay constant. Changes in governmental policies and energy trends, especially changes in market prices are excluded, even if very likely.

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[7] Calculated by the *International Energy Agency (IAE)* as *production of fuels + inputs from other sources + imports - exports + international marine bunkers + stock changes*. It includes coal, crude oil, natural gas liquids, refinery feed-stocks, additives, petroleum products, gases, combustible renewables and waste, electricity and heat [5, 17]. Electricity produced by conversion of primary energy is not included as it would have therefore been counted twice. Primary energy includes losses from conversion.

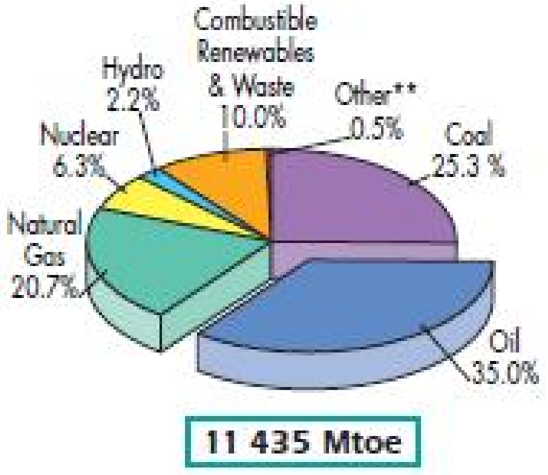

Figure 3: Fuel Shares of TPES by 2005 [10]

The scenario is based on key energy statistics and also assumes no scarcity of fossil resources.

3.2.2 High Growth Scenario

The *High Growth Scenario* is an assumption made by the IEA that India and China will extend their role in economic growth rates and energy demand. A proper boost, leading to higher energy prices is expected. This scenario is driven by high investments in China and India's industry and a decent increase of productivity.

3.2.3 Alternative Policy Scenario

The *Alternative Policy Scenario* is based on the assumption that highly developed countries will reduce their energy consumption and greenhouse gas emissions. The scenario also projects governments to apply energy policies including more sustainable forms of energy and limits for greenhouse gas emissions. However, the overall demand for primary energy will increase because of the demand of emerging countries, but slowed down by efficiency in production.

3.3 Greenhouse Gas Emissions

Among the assumption, that demographic and economic trends will proceed, world population is projected to increase from **6.5 billion** in 2005 to **8.5 billion** in 2030 [18]. In the *Reference Scenario*, the immense increase in world energy demand within the next

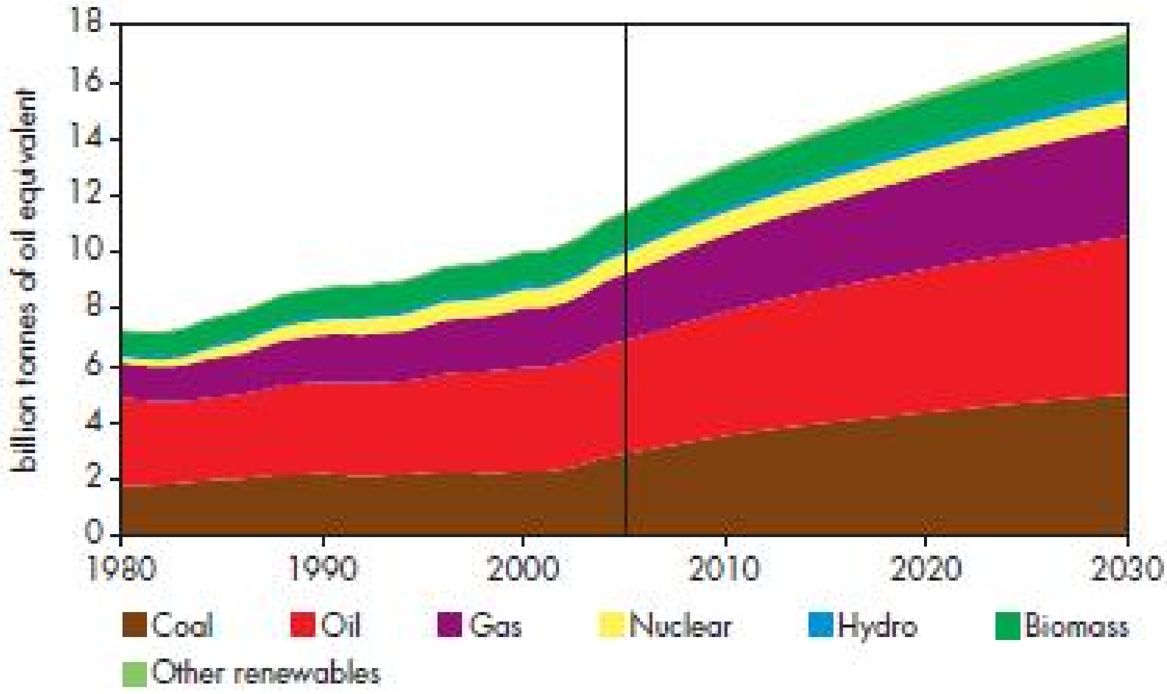

Figure 4: World Primary Energy Demand in the Reference Scenario [11]

20 years (up to *16.000 Mtoe*[8] by 2030 [11]) will be satisfied by fossil fuels [19], expecially coal and oil (as shown in Figure 4). In this scenario, renewables like wind energy, photovoltaic, hydroelectricity, biomass, tidal and geothermal energy will not be established widely. In consideration of the fact, that burning fossils is the most emission intense way to produce energy (see Figure 5), this scenario will lead to a higher concentration of carbon-dioxide (CO_2) in the atmosphere [18].

In 1987 the United Nations gave an abstract definition on sustainability:

> Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future. [1]

The share of greenhouse gases in the world's atmosphere increased rapidly since introduction of agriculture and industrial revolution. By now, the level of carbon-dioxide raised to approximately **380 ppmv**[9] within the last two centuries [20]. Thomas Stocker et al. state that in preindustrial times this level never exceeded **300 ppmv**. Furthermore, they found a strong coupling between antarctic temperature and the level of carbon-dioxide. For these reasons, it is inevitable to reduce GHG emissions within the next years to prevent earth and it's population from suffering from - by now partly unavoidable - impacts of an increased global average temperature in terms of a rising sea level,

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[8] Tonne of oil equivalent (toe). 1 toe = 0.041868 TJ. See [5] for conversion factors.

[9] Parts per million by volume = 10^{-6} = 0.0001 %

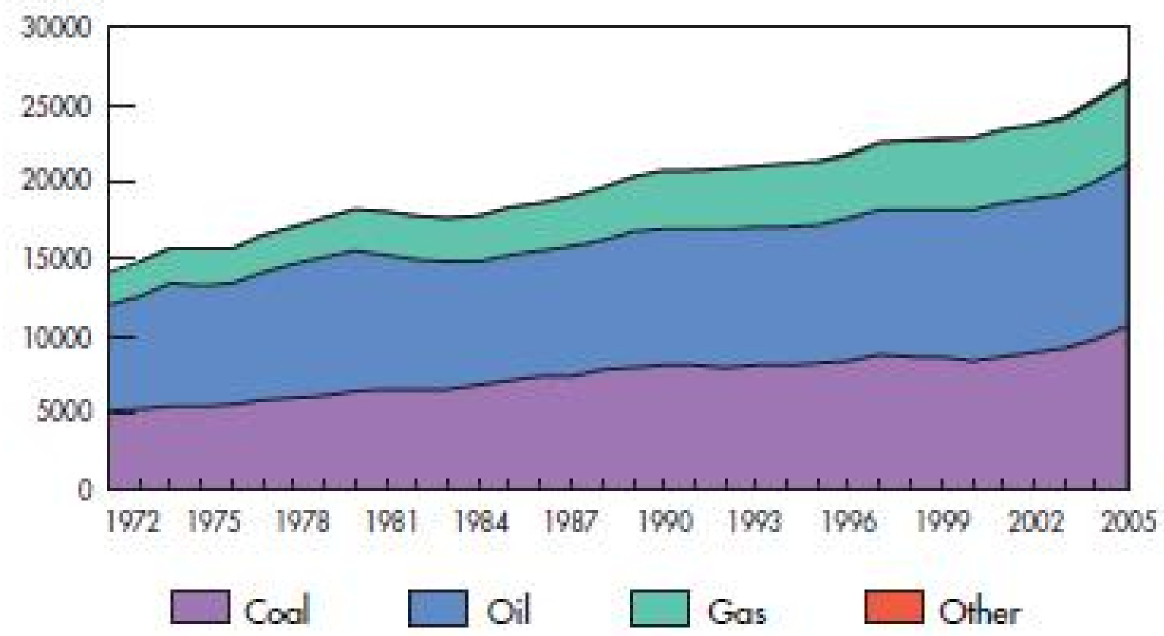

Figure 5: World CO_2 Emissions by Fuel (Mt of CO_2) [10]

scarcity of (drinking) water, drought periods and many more. Hence, the *Alternative Policy Scenario* must be taken into consideration and more sustainable forms of energy production applied.

3.4 A Shift in Composition

The previous section clearly pointed out, why it is important to reduce greenhouse gas emissions and reconsider energy production. The mixture of the energy production system of a country depends on certain influencing factors like geographical position (crude materials, coastline, mountains, wind), the political situation, governmental policies, the degree of advancement and many more. It is very vague to draw direct connections between one of these factors and for example the share of renewables, but it can be stated that highly emerging countries like China and India will be responsible for the vast majority of increases of GHG emissions [11] by 2030. In fact, economic growth and greenhouse gas emissions are coupled [13, 18] and the countries with the highest per-capita emissions are USA, Canada and Australia. But there are also high developed countries like Iceland or Norway[10] showing big demand for energy but have invested in cleaner renewables like geothermal power and hydroelectric energy production, meeting sustainability and furthermore durability.

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[10] Rank 1 and 2 by Human Development Index [18]

4 Granularity of Optimization

When comparing different approaches of monitoring and controlling energy consumption, it is vital to define system boundaries. Furthermore, global optimization can only be achieved when applying changes on higher levels, independent of the particular party controlling the regarding system. The consumption chain of electrical devices historically consists of three connected layers:

4.1 Optimizing the Power Grid

A sophisticated power grid is a vital element of modern and emerging economies with a high impact of technology. As the world's demand for electrical energy increases [11], the value of power grids will play a major role in future power supply and distribution. The *European Climate Change Programme*[11] aims to limit global increase of temperature to 2 °C by introducing the *European Union Greenhouse Gas Emission Trading Scheme* and reducing GHG emissions by using renewable energy sources. Many countries have changed or will change their energy policy and more sustainable forms of power production will come up or have already been integrated. Therefore, grids will face new requirements. On the consumption side, consumers will demand energy more flexible in both amount and location (imagine electrical powered cars). On the production side, new technologies like photo-voltaic, wind and tidal energy are getting part of public power supply. Moreover, consumers are becoming producers, supplying current from surpluses having wind turbines or photo-voltaic cells installed on their rooftops. A power grid that is capable of coping with these problems is called *Smart Grid* [21]. One of the biggest issues in a smart grid is information sharing. For energy producers, it is inevitable to track overall current consumption, load profiles and to create usage statistics. As a basic source of information on energy demand, smart meters are used.

4.2 Improvements on Consumer Side

On the consumer side, a distinction between industrial and individual consumers can be made. Households are connected to the lowest level of a power grid, which is 230V in Europe and 120V in the United States whereas industrial purchaser demanding excessive loads, are often connected to higher voltage and require organizational approaches e.g. re-scheduling of energy intensive processes. Furthermore, intensive monitoring can detect peaks, which lead to unnecessary costs because of exceeding limits of contracted energy supply. Considering households and individual persons, avoiding peaks is not a trivial task. First, individual needs and daily routines are distinctive attributes of our modern society. Postponing showering or cooking to off-peak times would not be a acceptable trade-off for many people. But, as there seems to be correlation between *gross*

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[11] http://ec.europa.eu/environment/climat/eccp.htm

domestic product (GDP) and energy usage [22], subsequently also a manner of greenhouse gas emissions [2], gaining more awareness for energy consumption of the home and in detail of single appliances by displaying load and prices will lead to reduction [4].

4.3 Optimization on Device Level

From a consumer's perspective, the device is the smallest unit of measurement and therefore of optimization. First of all, a device's characteristics in terms of energy consumption must be monitored. Furthermore, monitoring can detect inefficiency, malfunction, wrong usage and identify high costs. Devices must be comparable in terms of energy usage both before bought and when in use to gain more market transparency. Technical implementations of metering on device level are discussed in Section 6.3.

5 Typical Energy Consumption and Savings Potential

When comparing energy consumption, it is necessary to focus the context, which includes geographical location, human development and governmental aspects. We will focus on energy consumption of typical households in highly developed countries i.e. by definition of the *Organisation for Economic Co-operation and Development (OECD)* countries indicated by a *Human Development Index (HDI)* greater or equal than **0.800** because on the one hand, these countries are the world biggest per-capita consumers and on the other hand, they likely are primary target markets for smart meter vendors.

5.1 Per-capita Consumption

Reported by the *Human Development Report (HDR)* [18, 13], a typical EU citizen consumes **195 kWh/d** and an average American about **250 kWh/d**. According to MacKay [13], these numbers were higher because HDR does neither include energy needed to produce imported goods, which could have been calculated by using an Input-Output Model [23], nor naturally embedded energy, gained by photosynthesis [13]. These numbers show the high energy intensity of developed economics and sum up by a third for transport and mobility, a third for heating and cooling and a third for other stuff like light, gadgets, food and many more. Table 1 shows a detailed break down for UK citizens.

An interesting question is, how much of this energy goes into electrical power: Not much. As a vast majority of electrical energy is produced by burning fossil fuels (see Figure 3) [11] and conversion from chemical to electrical energy happens at an efficiency of approximately **30-40 %**, about a fifth of the energy supply results in losses. The energy consumed by a UK citizen, which is about **125 kWh/d**, splits up in **40 kWh/d** for heating, **40 kWh/d** for transport and only **18 kWh/d** for electrical devices.

Transport	35%
Hot air	26%
Hot water	8%
Light	6%
Process	10%
Other	15%

Table 1: Energy consumption by end use in UK [13].

5.2 Consumption in the Home

The majority of a typical person's energy consumption is spent on heating and cooling, electrical devices and light. Almost all of these components were spent in the home and at workplace. Table 2 splits up various activities like cooking, cleaning and cooling and shows load examples for the devices used. By applying changes in our daily routine, a significant amount of energy could be saved. According to MacKay [13], consumption could be reduced by **20 kWh/d** by turning down building heating to 15-17 °C. Another **4 kWh/d** can be saved just by switching from old light bulbs to LEDs (light emitting diodes). Darby [4] states that by giving direct feedback (metering consumption of electricity, gas or water), the amount of **5-15 %** of daily consumption can be saved. Energy monitoring tends to detect inefficiencies on device level, reduce peaks and give feedback about trends in consumption. In Section 6, we discuss modern monitoring approaches on different levels.

Device	Power	Time per day	Energy per day
Cooking			
kettle	3 kW	1/3 h	1 kWh/d
microwave	1.4 kW	1/3 h	0.5 kWh/d
electric cooker (rings)	3.3 kW	1/2 h	1.6 kWh/d
electric oven	3 kW	1/2 h	1.5 kWh/d
Cleaning			
washing machine	2.5 kW		1 kWh/d
tumble dryer	2.5 kW	0.8 h	2 kWh/d
airing-cupboard drying			0.5 kWh/d
washing-line drying			0 kWh/d
dishwasher	2.5 kW		1.5 kWh/d
Cooling			
refrigerator	0.02 kW	24 h	0.5 kWh/d
freezer	0.09 kW	24 h	2.3 kWh/d
air-conditioning	0.6 kW	1 h	0.6 kWh/d

Table 2: Energy consumption figures for heating and cooling devices, per household [13].

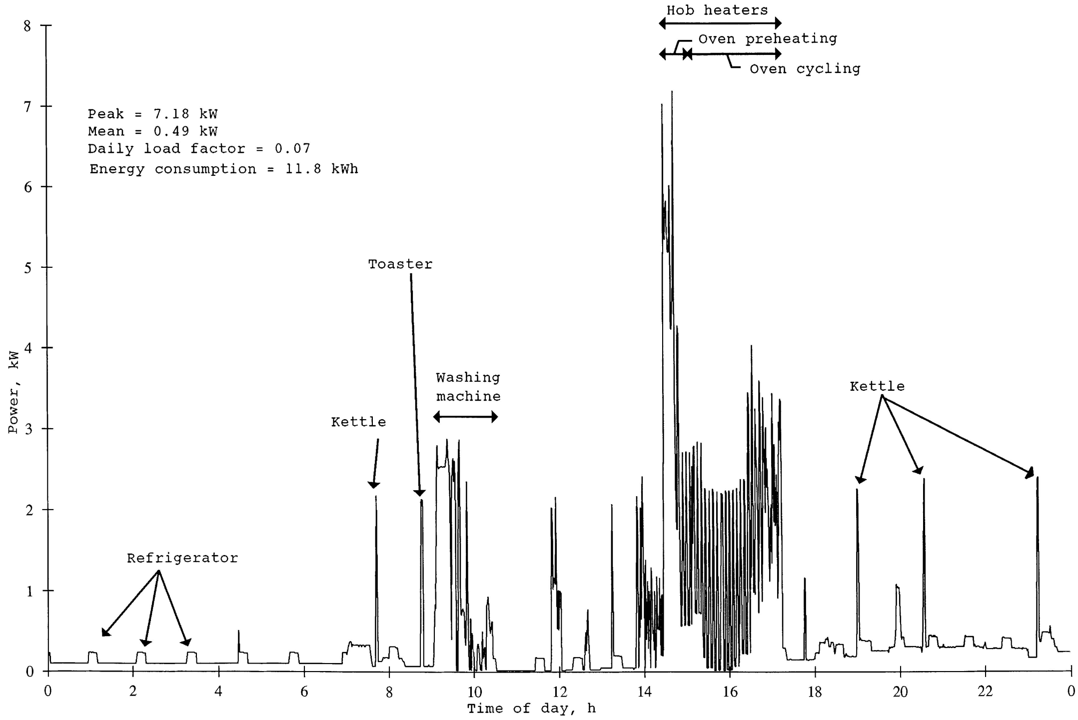

Figure 6: Example of an electricity demand profile from an individual household recorded on a 1-min time base [14]

6 Monitoring Approaches

6.1 Traditional Electric Meters

The traditional electric meter, used by electricity companies for accounting is the *electromechanical induction watt-hour meter*, shown in Figure 7. Its robust technical design is in use for over a century but is not capable of more than measuring the accumulated amount of consumed energy. A disadvantage is that either an employee, sent by the energy company or the customer himself has to read the meter manually which implies costs and administration effort. From the consumer's perspective it is fairly unacceptable to keep track of individual consumption, the load profile and recognize intense power consumption of individual devices by using a traditional electric meter.

6.2 Smart Meters

Smart meter is a very general term for a more advanced metering device, which provides more detailed information on consumption to the customer and is mostly able to com-

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[12] `http://upload.wikimedia.org/wikipedia/commons/4/40/Drehstromzaehler_offen.jpg` by MdE (Wikipedia-de), license Cc-by-sa-3.0

Figure 7: Three-phase electromechanical induction meter (opened)[12]

municate with the electricity supplier via some network for the purpose of accounting, billing and monitoring. Capabilities range from simple display meters, which gives a user feedback on current and past consumption, to high-tech meters which are capable of interacting with home automation systems and for instance are able to switch on a device when the supplier indicates cheap energy prices [26].

There are two main types of smart meters which are distinguished by their communication capabilities:

- *AMR Automatic Reading:* The communication is only one way from the meter to the data-collector.
- *AMM Automatic (or Advanced [8]) Management:* Two way communication enables a wider range of functionalities such as remote-activation, load-shedding, remote tariff-change and time-of-day tariffs.

Another distinction can be made in how the devices communicate:

- *Fixed:*
    - PLC (power line carrier)
    - Telephone land line (PSTN, ISDN, DSL, etc.)
    - Others (cable, fiber, m-bus (meter bus) etc.)
- *Wireless:*
    - GSM (SMS), GPRS, UMTS (standard mobile phone technologies)
    - Custom radio systems with different characteristics (short/medium/wide range)

Based on the previous characteristics a smart meter can provide some of the following features [7]:

- *Remote meter blocking* gives the possibility to turn power for a home on or off remotely. This can be used to get new customers connected faster or take customers off the net easily if they default on their dept.
- *Tariff management* provides the capability to manage multiple tariffs for different times of the day or week. The customer can then adjust his consumption in favor of a cheaper tariff which can help to prevent global consumption peeks.
- *Manipulation detection* helps to detect attempts to defraud faster.
- *Data maintenance* specifies the capability of the meter to store and access metering data of a time period.
- *Data processing* specifies the capability of the meter to calculate operating figures from the metering data.
- *Multi sector metering* aggregates metering data from other meters for gas, water or district heating[13] and integrates this information into the system.

Over the last years, vendors of smart meters, scientists and companies have created various web platforms to make collected data available to consumers. In this section we discuss two popular implementations and main features they cover.

Google PowerMeter [14]is an on-line service that interacts with consumers local smart meters via vendor or utility company. Load data is sent from a smart meter to the energy supplier, who forwards data to Google's data store (Figure 8 displays the schematic data flow) by implementing and invoking the *Google Data API*. Google provides a uniform user interface to all customers including processed and analyzed data. This technology leads to vendor independent information processing and allows integration of multiple devices. One of the disadvantages is the centralized storage of personal data (the consumer's load profile), although Google states not to connect consumption data to personal Google accounts[15]. PowerMeter was launched in early 2009 and has potential to become a widespread technology as many vendors have already rolled out smart meters with PowerMeter support[16].

Microsoft Hohm [19] is a web platform which uses information provided by the user about his building and energy usage to suggest ways how to reduce energy consumption. In difference to Google PowerMeter, this system does not have to be connected with a smart meter although there is a possibility to automatically collect the energy usage

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[13] Heat from a district heating network.

[14] Google PowerMeter, http://www.google.org/powermeter/

[15] Google PowerMeter FAQ, http://www.google.org/powermeter/faqs.html

[16] Distribution of PowerMeter as a Google Map, http://tinyurl.com/powermetermap

[17] http://www.google.org/powermeter/docs/powermeter-overview-for-utilities.pdf

[18] http://www.google.org/powermeter/docs/powermeter-overview-for-utilities.pdf

[19] Microsoft Hohm, http://www.microsoft-hohm.com/

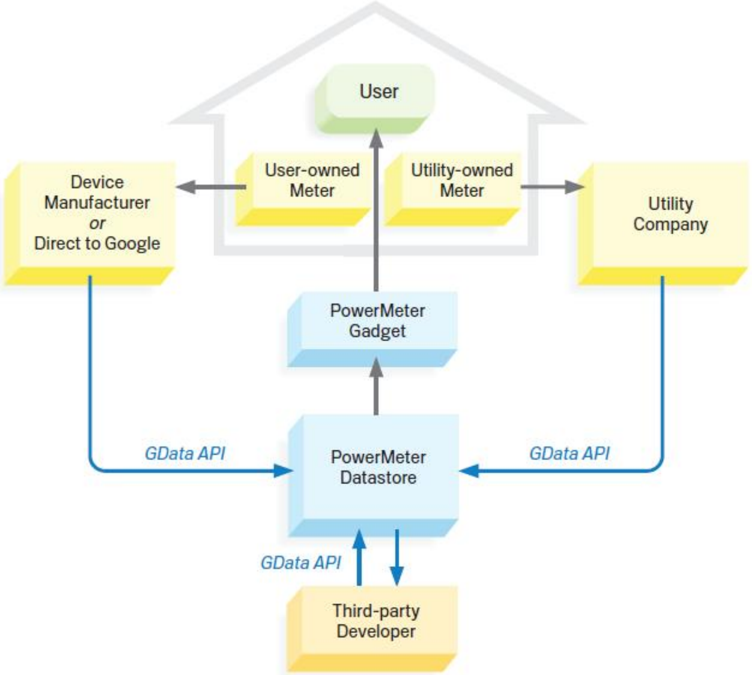
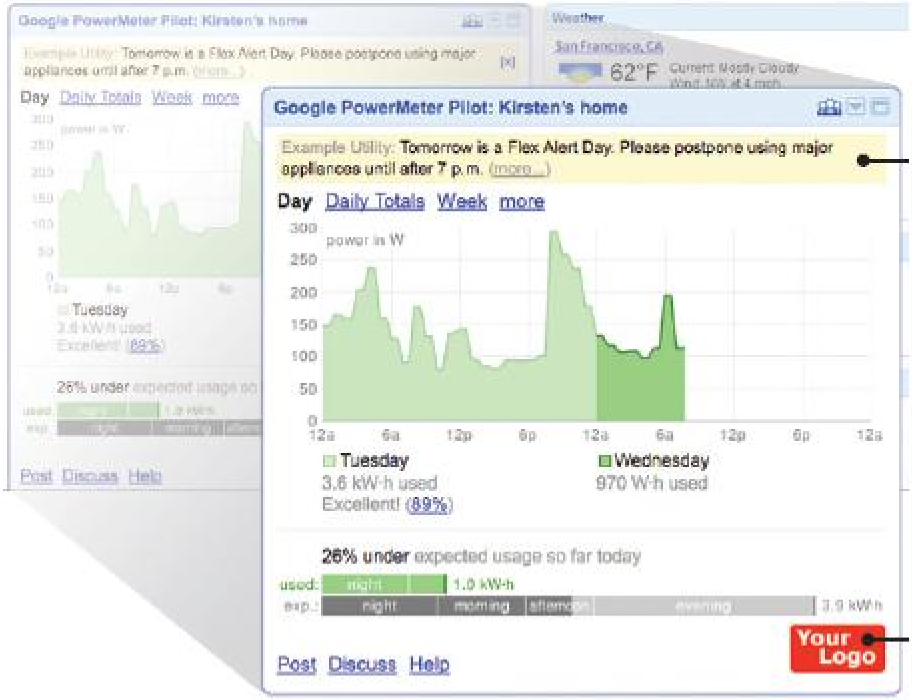


Figure 8: Google PowerMeter schematic data flow[17]


Google PowerMeter Pilot: Kirsten's home

Example Utility: Tomorrow is a Flex Alert Day. Please postpone using major appliances until after 7 p.m. (more...)

Tuesday
3.6 kW·h used
Excellent! (89%)

Wednesday
970 W·h used

26% under expected usage so far today

used: 1.0 kW·h
exp.: 3.9 kW·h

Figure 9: Google PowerMeter Web-interface[18]

data from cooperating energy suppliers. Microsoft Hohm was released July 6, 2009 and is only available in the US so far.

6.3 Metering on Device Level

Metering on device level indicates the amount of energy used by a single device, helps to identify inefficient or defect ones and gives hints on proper use of a device. Although it is a very simple technique, it provides a basic consumption profile of a device, which can be easily compared to other devices of the same kind (e.g. desktop computers, fridge, etc.).

6.3.1 Plug in electricity usage monitor

A watt meter for home use is plugged in between outlet and connector of an appliance an then typically measures:

- Voltage (Volt)
- Current (Ampere)
- Load (Watt)
- Energy (Kilowatt-hours kWh)
- Frequency (Hz)
- Elapsed time

The device displays the measured data and calculated data like the price of the used energy so far (see Figure 10). More advanced models have built in batteries to keep the collected data after being plugged out. The advantages of these devices are that they are relatively cheap[20] and easy to use. The downsides are that they only measure one appliance at a time and due to the lack of networking and communication capabilities, the aggregation of multiple devices must be done manually and can be time consuming and straining [12].

6.3.2 Home automation systems

A home automation system consists of "smart" devices and a communication bus that connects all devices in a home. The bus is usually used to control the devices but can also be used by the devices to send out their current power usage. From a technical perspective this is appealing as there is a fine grain picture of the current power consumption per device. Additionally the system has the ability to automatically optimize itself as the

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[20] The authors bought a device for 10 € in a supermarket.

[21] http://www.p3international.com/products/p4460.html

Figure 10: Example of a plug in watt meter[21]

devices can be controlled centrally. There exist various proprietary and open standards as well as implementations for home automation systems. None of these systems could really establish widespread acceptance in terms of absolute numbers. Another barrier are the high initial costs of such a system.

6.4 Non intrusive load monitoring

Non intrusive load monitoring is a technique to track down the exact usage characteristics and generated load of individual appliances by using sophisticated signal analysis techniques on the voltage and current waveforms. This technique only requires the information that is externally available from measurements of the load (e.g. by a traditional power meter). Hence, there is no need for multiple sensors placed on the appliances nor any cooperation from the residents [9].

7 Risk Analysis

Besides technical issues, the achievable energy savings will heavily depend on how good a social-technical system, economic or political circumstances will guide the users to change their habits to be more energy efficient and ecologic.

7.1 Acceptance

The acceptance of a technical system does not only rely on the proper technical implementation. Acceptance in general is defined as the willing to deal with a system. The establishment of for example a smart grid including smart meters must meet the acceptance of a certain percentage of the population to gain significant savings in energy consumption. Furthermore, it depends on industry and vendors adopting and implementing standards. Important factors for impairment or strength of technical systems are:

- *Trust.* It depends on the liability of the technical system as well as the surrounding system e.g. vendor running a system. Privacy can be violated through smart metering systems (see Section 7.4).
- *Monetary incentives.* Subsidies and pricing policies effect how appealing an investment is in economic terms. If people can save money by saving energy by using a metering device or companies can achieve more profit due to lower expenses, investments are more likely.
- *Comfort surplus.* Home automation systems aim for comfort surplus for consumers but are also able to yield potentials for energy savings.

7.2 Usability

Usability in terms of learnability, efficiency, memorability, error handling and user satisfaction is a crucial aspect in the design of systems that have to be used by end users without knowledge in the energy domain [15]. For wide acceptance, a smart metering system must be characterized by a steep learning curve. User interfaces must be easy to handle and content available through shallow navigation paths. Furthermore, user interfaces and content like figures or statistics must be suitable for persons of different age and knowledge (e.g. font size, language used) to be able to identify trends and adapt their individual energy consumption.

7.3 Information

Wood et al. showed that through information campaigns (e.g. posters about unnecessary lighting) only, measurable improvements in terms of energy consumption of participants can be achieved. This technique has a big disadvantage which is called the *Fall-back effect* [25], occurring after a campaign has ended and participants of the study forgot about the message and returned to their old consumption behaviors. Better results can be achieved with combined information and feedback about their behavior as an increase in energy consumption will be recognized.

Darby [4] basically distinguishes between direct and indirect feedback. Historic information on consumption (e.g. a monthly bill) is considered as *indirect feedback*. Consumers are able to track past energy consumption and detect trends. The savings potential, depending on the length of the feedback periods ranges between **0-10 %**. *Direct feedback* is given at consumption time by e.g. a smart meter and could save **5-15 %**.

7.4 Privacy

In 2008, the German energy supplier *Yello Strom GmbH* [22] was awarded with the ironic *Big Brother Award*[23] in the category *Technology*[24] for implementing a smart meter system that sends usage information of a single home to the energy supplier via power line and is also able to track individual devices that implement the home automation standard *DigitalStrom*[25]. The jury was concerned that the customer can not see or influence, which information is sent to the company, that there was not clear privacy protection policy and the whole system was prone to data abuse as detailed profiles can be generated from the collected data.

In 1987 George W. Hart was overly concerned that the *Non intrusive load monitoring technique* (see Section 6.4), he was researching on could impose a big threat to privacy. During his research he discovered, how easy it was to find out, whether someone was taking a shower or has made his bed (a water bed with heating). He also warned that it would be easy for repressive regimes to find forbidden printing presses or photocopiers. In his conclusion he suggests that electricity usage information should be considered as private as phone conversations [9].

8 Conclusion

In this work, the aspects of monitoring individual energy consumption were discussed. The complex connections of involved systems, energy production, greenhouse gas emissions and monitoring devices at various levels were explained. The fact that individual consumption can be reduced by monitoring and giving direct feedback to consumers leads to the establishment of smart meters and other load monitoring techniques as they are part of upcoming smart grids. Risks such as effectiveness, acceptance and privacy issues may occur and could lead to nonacceptance by consumers.

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About this Document

This thesis is part of the lecture series on *Sustainable Development and ICT*[26] held at Vienna University of Technology[27], Faculty for Informatics[28]. This thesis is part of a selection of submitted student-papers. This paper as well as all other papers are published under the *Attribution-Noncommercial-Share Alike* Creative Commons License[29] to provide a summary/impression from the students-perspective of the seminar for all that are interested in the topic, but could not participate. Other selected papers can be found online[30].

In case of questions, the authors Tobias Hochwallner and Lukas Lang can be contacted via email: hochwallner.t@gmx.at, lukas.f.lang@gmail.com. The organizer and supervisor of this lecture series was Alexander Schatten[31].

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