Internet Science – Energy Consumption and Optimization

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ABSTRACT

Energy saving is a mandatory part of environmental protection. At the same time it is difficult to get an overview what influences energy consumption and conservation. Therefore, a quick overview from statistics about energy usage is presented, focusing on private households and consumers. It is followed by an introduction to several methods aiming at consumer's behaviour to save energy. Starting from providing simple energy-information to users, more concepts like feedback, competition, pricing pressure or influencing decisions are discussed. The last section shows typical problems like personal habits and routines, industry and marketing or the rebound effect, that emerge along energy-saving scenarios, using the results from the previous insights.

Keywords

Energy, Consumption, Save, Environment, Smartmeter, Consumers, Behaviour, Influence

1. ENERGY CONSUMPTION OVERVIEW

Our whole life is governed by energy. We either consume it directly by turning up our heater or unwittingly by triggering an online search. However, only a minority of people really knows, how much energy they are consuming all day through. Energy just seems to be an abstract thing, everybody pretends to know about. It is available every time we need it, but in fact, most of the time we really don't care about energy. However, there exist these situations where energy comes to our mind, for example the moment when we open our energy bill, or when we see a TV report about ice bears struggling with melting ice floes.

In the first part of this work, we'll take a look at the amounts of energy that is actually consumed at daily basis. There is plenty of energy-statistics available, but most of them are quite abstract due to the fact that they aggregate the numbers of thousands or even millions of people. Therefore, our main goal is to get an impression about the proportions of different energy-consuming fields and to identify the real power-eating technologies peoples are dealing with.

1.1 Energy Consumption by fields

The most abstract view on energy consumption is given by a summation of the total required energy for a country like Germany, the so called *Primary energy consumption*. It includes all raw energy forms that are used to satisfy the demand both on production goods (*Non-energetic consumption*) and secondary energy like electrical energy or fuel (*End-energy consumption*).

In 2012, Germany had a *Primary energy consumption* of about 13757 PJoule (fig.1). Thereof, 7.1% (978 PJoule) were transformed to production goods and only about 65.4% (8998 PJoule) went further as *Secondary Energy*. Unfortunately, the remaining 27.5% (3781 PJoule) rested in the conversion from raw energy sources as coal or natural gas to goods or secondary energy. In other words: about one third of our used energy is lost – before even using it [5].

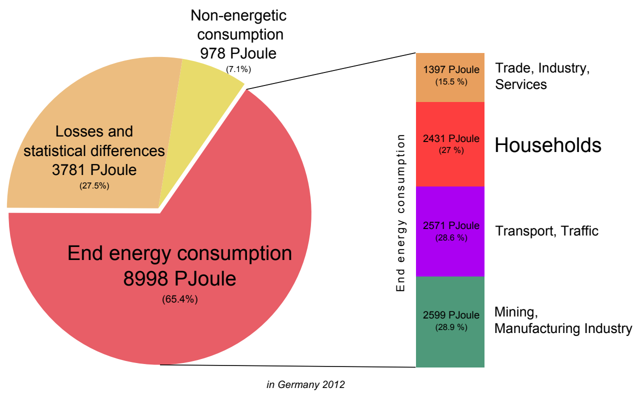

Figure 1: Primary / Secondary energy consumption in Germany 2012 [5]

If we now look at the produced *secondary energy*, we can distinguish four main fields of usage. The biggest consumption share has heavy industry and mining sector with 2599 PJoule (28.9%). Second largest field is traffic and transportation (2571 PJoule, 28.6%). With about 27% (2431 PJoule), private households go on rank three, followed by Trade, Industry and Services (1397 PJoule, 15.5%).

Thus, private households energy demand is about 18 percent of the total German primary energy consumption.

1.2 Private Energy Consumption

As we're interested in the Optimization Potential for consumers, we turn special attention to statistics regarding the use of energy in private households.

Figure 2 shows the average distribution of energy use in German households for 2010. Each histogram bar represents one typical energy source, as they appear for domestic use. The colours indicate the different application fields like *Room heating*, *lighting* or *information technologies*.

The most obvious fact from fig.2 is indicated by the large share of red blocks, which symbolize energy spent on heat-

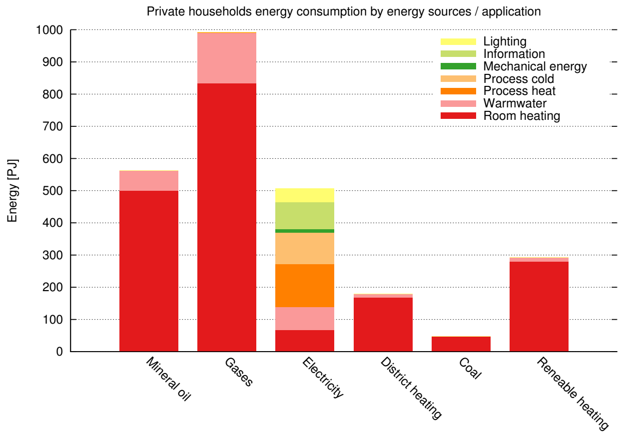

Figure 2: Private households energy consumption by energy sources/application in Germany 2010 [6]

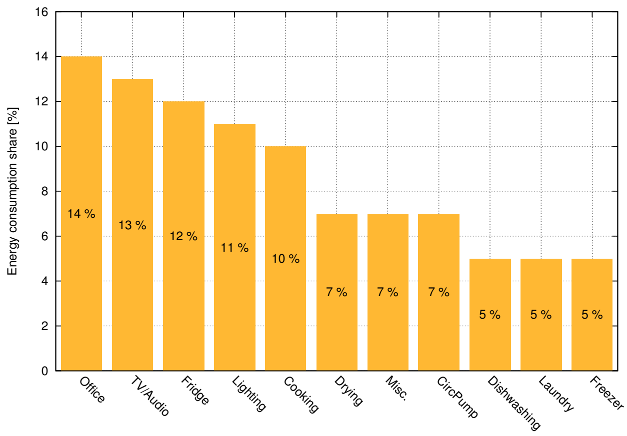

Figure 3: Energy consumption shares (without heating, German study 2011 [4])

ing. About 85% of private households energy is needed for the heating of rooms and warm water.
That means in turn, that only about 15% of domestic energy consumption is coming from general electric devices.
A report made from 380.000 datasets in 2011 attempts to demonstrate domestic energy usage, excluding heating and warm water (fig.3). It states that office equipment forms the largest share (14%) of electrical power, followed by TV and Audio devices (13%), the fridge (12%), lighting (11%) and other household devices [4]. Replacing the term *office equipment* with *computer equipment*, we get – together with the TV and Audio part – a share of 27 percent for end users Information and Communication Technology devices.

To get an impression of today's energy consumption values and its costs, the author did some measurements in his own household. Table 1 is divided into two categories. The first part *Long term energy consumption (per year)* lists some extrapolated values for the long term use of typical devices, the second part *Short time energy consumption (per use)* focuses on devices with high but short loads and presents the costs per use. The results suggest, that costs measured

Long time energy consumption (per year)			
Fridge:		202 kWh/a	47.14€/a
Desktop-PC1:	~120W	311 kWh/a	72.48€/a
Desktop-PC2:	~80W	145 kWh/a	33.78€/a
Notebook:	~15W	26.3 kWh/a	6.11€/a
Router:	~7W	37.8 kWh/a	8.80€/a
NAS (2bay):	~15.5W	134.5 kWh/a	31.34€/a
Short time energy consumption (per use)			
Laundry (40°):		0.58 kWh	0.14€
Water kettle (1L):	~2200W	0.13 kWh	0.03€
Microwave:	~500W	0.03 kWh	0.01€
Espresso:	~1000W	0.04 kWh	0.01€
Vac cleaner (15 min):	~1000W	0.25 kWh	0.06€
			@ € 0.233/kWh

Table 1: Own measurements of typical household activities

per use seem to be quite low compared to the estimated annual costs for longer used devices. Another issue is the growing number of always-on devices. Most of them have low wattages, but viewed together and for a long period, they sum up to a quite considerable cost factor.

1.3 Trends and change in Energy use

Energy use can not be seen as a static quantity, it is always varying over time. This is also one of the reasons, why people often have difficulties comparing energy consumption values.
If we look at the German energy consumption of the last twenty years, at first glance, there seems to be no big change over time (fig.4).

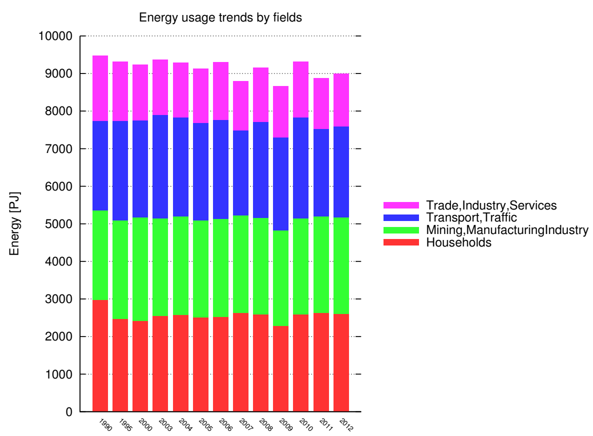

Figure 4: Energy usage trends by fields

But taking into consideration the units scales of the graph, the amount of yearly used energy is actually fluctuating by about 500 PJoule. 500 PJoule correspond to about 138.9 billion kWh, that is approximately the electricity consumption of Norway in 1998 (according to WolframAlpha). This also illustrates the fact, that humans have difficulties to grasp energy consumption values, especially with high quantities or absolute numbers.

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Special observance is required for the fast changing ICT sector. Figure 5 from [13] visualizes the worldwide energy consumption for Information and Communication Technology. Whereas the rising number of LCD-monitors eats up the energy saving inducted by replacing CRT- by LCD-models, there is a clear trend towards a more demanding network sector. In almost the same manner, Data centers grow continuously and consume more and more energy. Overall, the share of ICT products in the global electricity consumption has grown from 4% in 2007 to 4.7% in 2012 and the recent growing rate of worldwide electrical ICT consumption is estimated at 6.6% per year [13].

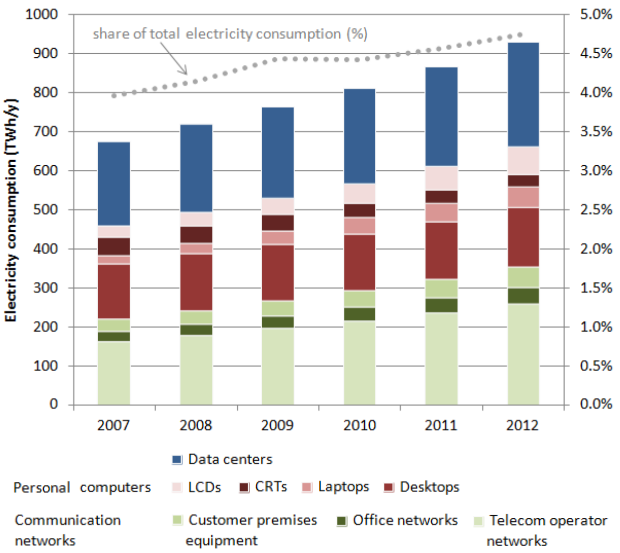

Figure 5: Trends in ICT energy usage (cf.[13])

2. SEVERAL IDEAS TO MAKE PEOPLE SAVE ENERGY

Nearly as long as there had been energy use, people have made attempts to save energy. Originally, the saving has been motivated by limited resources, but over the last decades, several new goals like climate protection and sustainability appeared.
There is a huge innovation market for energy-saving technologies, and almost every industry promotes its products as *environmental friendly*. What many companies disregard, is the *human factor* for energy saving. Technology can only be used effectively and energy-saving, if people use it the right way. Polls have shown, that consumers are willing to save energy, and feel themselves as *energy-aware*: ”66 percent of global consumers say that they prefer to buy products and services from companies that give back to society” [2] and a representative survey of the German Department of the Environment concluded, that about 78% of German people consider themselves as sufficiently energy-conscious and ecology-minded [10].
The following section will present some concepts that tempt to make people save more energy, beginning with the most simple, then going to the more demanding and sophisticated methods.

2.1 Information

The most straightforward approach to make consumers save energy is to inform them about energy consumption. Such consumer information often comes in brochures, flyers and is typically provided by the energy suppliers, the authorities or some other institution that either wants to gain reputation or just has financial benefits from that information campaign. Providing general information is by far the easiest and cheapest method to reach better energy saving, but the impact on energy consumption is known to be very little [10, 2, 9, 14]. It turns out, that users are basically not able or willingly enough to transform the received information into practice. General information seems to have a lack of some basic principles of human behaviour: Mainly it is missing *Motivation*[9, 14] and *Feedback*[19].
An example from [2] demonstrates this fact. In 2009, all fast-food restaurants in New York City were forced to label their menus with calorie-count information. The desired effect – reducing obesity rates – did not arise.

However, there are several ways to improve the results of information about energy saving. One critical parameter is time. If information is given frequently, the user will tendentiously be more motivated to deal with the proposals [9, 19] and thus it is more likely that the information really reaches the recipient.
Other projects make use of target-group-specific mediators like students or children, that were trained as *Energy advisers*. They should take advantage of the affinity to their audience, to help imparting the knowledge about energy saving.

2.2 User specific Feedback and Smart-meters

Households differ in many ways, therefore providing universal energy-saving advice is a difficult task. Quite better results can be obtained by giving user-specific feedback concerning the amount and time of consumed energy. By identifying the user’s individual consumption, most power-eating devices and power-wasting habits, the feedback generation is able to adapt exactly to the needs of the consumer. At the same time, feedback helps to direct the consumers attention towards *specific goals* [14] and has the potential to ensure *long-term motivation*.

There are various types of energy feedback generation. A simple form of feedback is the energy bill, that every consumer receives regularly. Typically, it states the used amount of energy since the last bill. Feedback with energy bills is quite easy to implement, and that’s why it has to be considered, although it is not the best method for long-term motivation. Here, the quality of feedback mainly depends on the time interval the bills are sent in, the visualisation of the numbers and a comparison or ranking that allows the people to get an idea about their consumption status [9, 12].

More precise feedback can be achieved with the help of *Smart-meter* measurements. A Smart-meter normally replaces the old power meter at the consumers house, and then constantly records the energy consumption level over time, ranging from 15-minutes intervals over 1-hour intervals up to daily consumption reports. Smart-meters differ

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in the way they publish collected information. The original Smart-meters were designed to inform the power suppliers about the current load of their customers. From that data, they are able to forecast peak-load times and to maintain the grids efficiency and stability. Unfortunately, this centralized approach led to a perception of Smart-meters as a form of supervising, user-controlling system [1].
This impression from the users influenced the technology to make the information also available for the consumers. Most of these systems just allow the consumer to login to a web-portal, where they can browse through their latest energy consumption history, and some of the systems even give hints and tips for smarter energy usage or show the environmental impact.
A key point for good Smart-meters is the detection of *device-specific consumption*, and thus providing a detailed view about the households energy profile. There exist new algorithms that allow the user to train his Smart-meter for a certain device, just by pressing a train button and then switching the device on and off. The device signatures that are extracted like that, can then be used for improving the feedback information, or it can be uploaded and aggregated in comparison databases, so that Smart-meters are able to estimate, which device was powered on, even without training from its user [19]. Several projects go the other way round, they include tiny Smart-meters in every device, either sending the consumption values to the central Smart-meter, or displaying it directly on the device.
Especially the last approach seems to quite successful, as it gives information to the user in the exact moment, when he uses the device and thus has the potential to change following actions: "Oh, the heater used so much? Mhh, I should turn it down now...".

Despite all advantages of Smart-meters there are also some downsides. First, the mentioned privacy and security issue. Secondly, many Smart-meters use their proprietary interfaces, which decrease interoperability. Then, users have to accept the received feedback and turn it into practice. Anyway, the long-term motivation of users seems to be the hardest point to achieve. For example, a German field experiment found out, that after two month of web-based feedback, only about 5% of test-consumers still seriously used the webportal. We will see some of the assumed reasons for that in the next chapters.
One last drawback is the acquisition costs for Smart-meters, that are not easy to amortize by energy-saving. The range of achieved energy savings with feedback information goes from negative savings – more on that later – to usually 5% to 10%, in rare cases up to 20% [9, 12, 14]. This percentages will often not be enough to compensate the price of modern Smart-meters.

2.3 Motivation from interactive comparison and competition

Informing the user and giving feedback is only the first step towards reasonable energy saving.
Behavioural experts see information as the base layer of a behavioural model, which leads to consciousness about a problem or individual possibilities. The second stage is formed by implicit and explicit comparisons. The implicit comparisons are made by *social and personal norms*, whereas the explicit comparisons are based on hard facts like the energy bill, historical consumption feedback or comparisons between users (See [9, 14]).
We already found out, that *setting energy-saving goals* is one of the key points to achieve good energy savings. Therefore, the main focus should go to *comparable feedback information*, that clearly shows the consumer, how his energy footprint performs compared to other users/households with different appliances and usage strategies. After receiving optimal feedback, the consumer will then develop self-set improvement goals, thus directing more attention to the respective tasks [14].
For the formation of this goals, the social environment and its interactive component is often underestimated. If a consumer is confronted personally with a low conservation goal, he is more likely to accept higher goals afterwards. This method is called the "foot-in-the-door technique" and can be used for raising better energy saving goals, especially for an effective introduction to energy saving [14].

At the same time, it is also highly important to keep *long term motivation*, for example by providing interactive elements and decision points. The most obvious method is to promote competition between consumers. "*Gamification*" of energy saving among friends has great potential to motivate consumers and to get them interested in energy saving. Games can also be used for training environmental and energy-aware behaviours, as they provide both interactive and motivating concepts [16, 1, 19].

There had been several projects with collaborative and interactive energy-feedback systems. "PowerPedia" is one example for a social, energy-profile sharing Smartphone application. Users can measure their devices in realtime, and compare them either with devices from a community-driven online database, or just with friends over social networks [19]. The integration of energy feedback in *existing systems* (smartphones, social networks, etc.) is a necessary task, because users should keep *regular contact* with their energy reports, so that they can react on occurring changes immediately. Considering all these advantages, knowledge transfer from the games industry to the energy saving field is imaginable and highly recommended.

2.4 Price-driven energy saving

According to the economic principle of demand and price, high energy prices should also decrease energy consumption. So the assumption is, if energy becomes less affordable, consumers will automatically try to save energy.
A short look on the facts reveals a price increase for German Electrical Energy from €16.65/kWh in 2000 to about €25.14/kWh in 2012 (+51%), that was mainly influenced from the German *EEG reallocation charge* [8]. For exact the same period of time, the consumed energy has also risen from 1780 PJoule (2000) to 1869 PJoule (2012) (+5%) [5]. Assuming unchanged technological conditions, this may suggest, that consumers are not fast enough to adopt to changing energy prices by reducing consumption.

The same conclusion comes from a Swiss study, aiming at the *price elasticity* of households [17]. It states a very low and slow reaction to rising electricity prices, mainly caused by insufficient consumer knowledge on how to save energy.

But who knows, perhaps one day, the continuing increase of the *EEG reallocation charge* may have a positive impact on energy conservation.

2.5 Taking control of user decisions

Sometimes, feedback information or even high energy prices may not be enough to trigger ecological-friendly behaviour. Due to the overwhelming complexity of modern systems, it is difficult for the consumers to identify the right decisions at the right time, only based on the abstract information they get. The field of decision consumers have to deal with, ranges from buying-decisions in the markets down to setting their washing machine temperature. There exist situations, where consumers need the help of an advisor or *decision maker*.

For Smart-meters, the decision maker is a device connected to the user's *Smart Meter Gateway*. It is controlled by the *Smart Meter Gateway Administrator* (mainly the energy grid operators), and can cut the power in case of power shortage or when the user consumed energy far over normal level. In such cases, the consumer is first informed about the situation in order to reduce the current load. If no action follows, the Smart Meter Gateway will partially shut down energy lines [3, 1]. In reality, however, these smart decision makers are still rare and only tested among industrial consumers.

But the concept of influencing consumer decisions is promising in various ways. It is fact, that several fast decisions in tiny moments can have a major influence on our energetic footprint. If we manage to identify these "crucial moments" [2], and provide "decision helpers" for them, we can avoid massive energy consumption. The article from Dan Ariely and Aline Grüneisen [2] proposes to use children to effectively train their parents behaviour towards environmental-friendly decisions, like buying energy-efficient lamps instead of conventional light bulbs.

In 2009, the European Union pioneered the "control-driven energy saving" by imposing legal prohibition on inefficient light bulbs. The consumers reacted with rage and some of them found clever ways to circumvent the ban, for example by selling "small heating devices" that look like light bulbs, but are officially used for heating.

A more encouraging approach comes from user experiments with the so called *anchoring bias*. The assumption is, that consumers are highly influenced by predefined default parameters, when using their appliances or making decisions. Researchers figured out a low-level cognitive link between consumers decisions and the decisions of their environment, so that they unconsciously try to orientate their choices on existing decision results [14].
For the industry, that implies a conscientious adjustment of default settings for energy-consuming devices, because consumers will mostly trust the parameters predefined by the manufacturers. In return, companies that do not care on reasonable energy-presets, should be outlawed by society.
A good *negative example* to study, is the new generation of gaming consoles *Playstation 4* and *Xbox One*. They both implement the new EuP-energy-saving standard, that demands a standby consumption under 1Watt, but in fact, neither Sony or Microsoft enable it by default. Despite that, the *Xbox One* has a default standby consumption of 19 Watt and *Playstation 4* draws 6 Watt. Not enough, both manufacturers prevent the users to enable the real energy-saving mode by extremely long loading times and inconvenient handling [7].

3. MAIN REASONS FOR PROBLEMS IN ENERGY SAVING

As presented so far, there is a lot of effort to reduce energy consumption. Technological progress allows the development of smart energy saving systems and maximizes the effective output of appliances. However, energy saving is not only achieved by technology (*hard energy-saving factors*), but also by the users behaviour and lifestyle (*soft energy-saving factors*) [10]. For the *soft* factors it is important to know both sides that influence consumers: the reinforcing strategies and also the points that discourage users to save energy. In the following, we look at some of the effects counteracting energy conservation.

3.1 Personal comfort: Habits and Routines

Typical consumers have no time to think about energy. They are stuck in *daily business* and their *routines*, and are simply not aware of any *energetic problem*. Other problems seem to be more important, and so there is little to no effort made for energy saving.
Some users are one step further, they already *identified* potential *energy saving spots*, but they are lacking the required knowledge how to save. At this point, even if consumers acquired the needed *knowledge about energy conservation*, many have *fears* turning it into practice [10].
For example, choosing a smaller and more economical car is a commendable step towards climate protection, but many consumers like their car as sort of a status symbol and hence would never go without it. Here, anxieties come from apprehended *restrictions* and from fears towards *social isolation* caused by reduced lifestyle [10].
Another barrier, that has negative influence on energy saving, are the still too low energy prices. Taking some citizen's Christmas illumination as an example, it seems, that *wasting energy is still affordable and tolerated by society.* If energy prices were higher, or perhaps coupled to usage scenarios, there would be more motivation from consumers point of view to save energy. There exists no real consequences for irresponsible energy use, despite the pure energy costs, which are nonetheless affordable by *wealthy energy wasters.*

For all that reasons, it seems especially important to have some sort of energy saving pioneers (In [18], they are called *sociometric stars*), that act as role models for consumers and help them to overcome their passive behaviour. Users should be given reasons, why it is exactly them, that have to save energy. At the same time, irresponsible usages of energy should be denounced more heavily in public.

3.2 Influence from Industry and Advertisement

Today's consumers live in a commercialized world, that is dominated by a huge number of profit-orientated companies. These companies – and in particular the corresponding

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Figure 6: Forces against Behavioural change for energy saving (cf. [10])

marketing departments – have the goal to promote and sell their products, regardless of the energetic impact for customers. Compared to the number of marketing employees, environmentalists are largely outnumbered with their efforts to show energy-efficient living.
We in the role of customers are already used to the "shiny" products from the industry, and let them influence our decisions what to buy or to use. For example, a producer of electrical-powered heaters advertises his products as cheap and simple to use. Attracted by the advertising promises, consumers buy the heater with the aim to get a cheap and fast heating. Later, it turns out, that the manufacturer of the heater concealed the high energy consumption and costs, just to achieve larger sales.
The omnipresent manipulation from the industry makes it difficult for consumers to adopt to energy-friendly behaviours. It demands much endurance and a strong-minded behaviour to resist against all the attractions that economy provides with its markets.

3.3 Unclear return on investment for energy-saving

Effort for energy saving technologies is also dependant on economical circumstances. In 2012, the European Union appealed for a 80%-deployment of Smart-meters until 2020, under reserve, that the overall result is positive. Therefore, a call for studies to evaluate the benefits of Smart-meters was raised. For that, every country investigated the economic potential along with deployment and other issues. Austria for example concluded a positive outcome, they calculated the total required investment to about €4.4 billion, linked to a energy saving worth €5 billion (29.6 TWh) for 2011 to 2017. Surprisingly, Germany predicts a negative outcome. Here, they estimate the investment to €21 billion, with only €6.4 billion as efficiency gain between 2014 and 2022 [15, 3, 11].
Again, the decision for – or against – a specific energy-saving technology *depends on the information we have* about it. Here, the Austrians decided to invest in the broad deployment of Smart-meters, whereas the Germans will first introduce Smart-meters for large-scale consumers with over 6000 kWh per year.
Regrettably, choices are generally not only made by rational thoughts. Instead, choices are mostly based on very limited, estimated or even wrong facts [18]. For the domestic energy consumption this typically includes the *monthly bill* (made from interpolated values), *remembered usage history* and *personal perception* of the energetic environment.
All in all, economists regard analyses on energy use as a hard problem, because it is influenced by various determinants like consumer *behaviour*, *technology* and energy *pricing* [18].

3.4 Underestimated Rebound Effects

By far the most undesirable effect that counteracts energy saving, is the so called *Rebound Effect*. The Rebound Effect describes the behaviour of consumers, who overreact after a successful energy-saving change: With the first operation of a new saving technology, consuming energy may become cheaper or easier, resulting in more extensive use than before. If the additional consumption eats up the saved energy benefit, it causes the *Rebound Effect*.
The classical example is the deployment of a new central heating, replacing de-central heaters. Heating rooms is now simplified, and therefore more rooms are being heated, which can lead to even higher energy use than before [10].

4. STEPS TOWARDS BETTER ENERGY USAGE

To understand, how and why people are saving energy, you have to look at different aspects simultaneously. First, an evaluation of the current situation has to be established, by creating *significant energy consumption statistics* in the desired energy-sector and gaining an insight to *user's habits and life*.
From that stage, ideas can be developed, how to guide consumers to better energy usage, for example with *personal feedback* or *interactive methods*. *Behavioral science* tells us some principle aspects like *long-term-motivation*, *goal-setting* or *anchoring bias*, that always have to be considered when thinking about user-involved processes. The potential coming from gaming and social comparisons also seems particularly promising here, but it needs to integrate seamlessly into the life of consumers.

Creating energy saving plans is also *highly complex*, and identifying concepts, that have *positive benefit and low costs at the same time*, is not easy. Especially *several industries* and *markets* are hard opponents to efficient energy use, because they often manage to interfere energy perception or long term energy plans.

It also turned out, that many decisions for energy-related topics are made using *wrong information*, *inaccurate estimation* or *vague perception*, resulting in *undesired symptoms* like the Rebound Effect. Sometimes it may even be useful, to *take control over consumer decisions*, simply to prevent irresponsible energy wasting.

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